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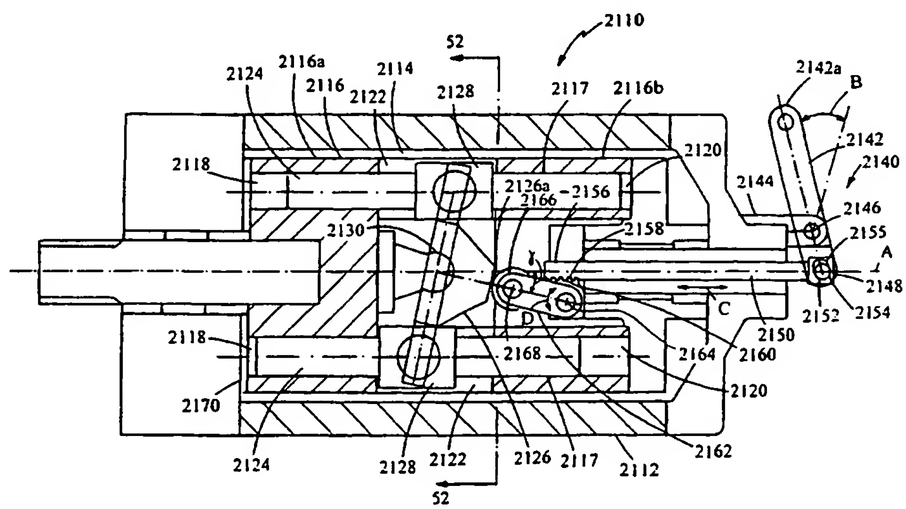
(54) Title: PISTON ASSEMBLY



(57) Abstract: A hydraulic pump includes a housing, at least two pistons mounted to the housing to rotate relative to the housing, and a transition arm coupled to each of the pistons to rotate therewith. The transition arm is set at a predetermined angle relative to a longitudinal axis of the pump. An adjustment mechanism sets the transition arm at the predetermined angle. A cylinder is mounted within the housing to rotate relative to the housing and defines pump cavities for receiving the pistons. A face valve defines inlet and outlet channels in fluid communication with the pump cavities. An apparatus for varying the output volume of a piston assembly includes at least two pistons, a transition arm coupled to each of the at least two pistons, and a rotatable member. The transition arm includes a nose pin, and the rotatable member is coupled to the transition arm nose pin. A radial position of the nose pin relative to an axis of rotation of the rotatable member is adjustable while the rotatable member remains axially stationary.

WO 01/11237 A1

PISTON ASSEMBLY

Background of the Invention

The invention relates to a piston engine assembly.

Most piston driven engines have pistons that are attached to offset portions of a crankshaft such that as the pistons are moved in a reciprocal direction transverse to the axis of the crankshaft, the crankshaft will rotate.

U.S. Patent 5,535,709, defines an engine with a double ended piston that is attached to a crankshaft with an off set portion. A lever attached between the piston and the crankshaft is restrained in a fulcrum regulator to provide the rotating motion to the crankshaft.

U.S. Patent 4,011,842, defines a four cylinder piston engine that utilizes two double ended pistons connected to a T-shaped connecting member that causes a crankshaft to rotate. The T-shaped connecting member is attached at each of the T-cross arm to a double ended piston. A centrally located point on the T-cross arm is rotatably attached to a fixed point, and the bottom of the T is rotatably attached to a crank pin which is connected to the crankshaft by a crankthrow which includes a counter weight.

In each of the above examples, double ended pistons are used that drive a crankshaft that has an axis transverse to the axis of the pistons.

Summary of the Invention

According to one aspect of the invention, a hydraulic pump includes a housing, at least two pistons mounted to the housing to rotate relative to the housing, and a transition arm coupled to each of the pistons to rotate therewith.

Embodiments of this aspect of the invention may include one or more of the following features.

The pistons are double ended pistons. Each double ended piston has a first end and a second end and the transition arm is coupled to each of the double ended pistons between the first and second ends. The transition arm is set at a

Embodiments of this aspect of the invention may include one or more of the following features.

The rotatable member defines a channel for receiving the nose pin. A bearing block is configured to slide within the channel. The channel is arc shaped such that the bearing block slides along a circumference of a circle. A bearing is mounted in the bearing block to receive the nose pin. The bearing block includes gear teeth. A drive gear engages the bearing block gear teeth to actuate sliding of the bearing block within the channel. The rotatable member is configured to vary the piston stroke to a zero stroke. The pistons are single ended pistons having a piston at one end and a guide rod at an opposite end.

According to another aspect of the invention, a method of varying the output volume of a piston assembly includes providing a piston assembly having at least two pistons, a transition arm coupled to each of the pistons, and a rotatable member coupled to the transition arm nose pin. The method includes moving the nose pin relative to the rotatable member to adjust a position of the nose pin relative to an axis of rotation of the rotatable member while the rotatable member remains axially stationary.

Advantages of the invention may include one or more of the following features. A hydraulic pump is disclosed employing double ended pistons in which only one valve plate is needed to provide fluid communication to both end of the pistons. A piston assembly is disclosed having output volume adjustment down to zero stroke while maintaining the ability to handle high torque loads.

Other features and advantages of the invention will be apparent from the following description and from the claims.

Brief Description of the Drawings

FIGS. 1 and 2 are side view of a simplified illustration of a four cylinder engine of the present invention;

FIGS. 3, 4, 5 and 6 are a top views of the engine of FIG. 1 showing the pistons and flywheel in four different positions;

FIG. 24a is a side view of the transition arm and universal joint of FIG. 24, taken along lines 24a, 24a;

FIG. 25 is a perspective view of a drive arm connected to the transition arm of the piston assembly of FIG. 22;

FIG. 25a is an end view of a rotatable member of the piston assembly of FIG. 22, taken along lines 25a, 25a of FIG. 22, and showing the connection of the drive arm to the rotatable member;

FIG. 25b is a side view of the rotatable member, taken along lines 25b, 25b of FIG. 25a;

FIG. 26 is a cross-sectional, top view of the piston assembly of FIG. 22;

FIG. 27 is an end view of the transition arm, taken along lines 27, 27 of FIG. 24;

FIG. 27a is a cross-sectional view of a drive pin of the piston assembly of FIG. 22;

FIGS. 28-28b are top, rear, and side views, respectively, of the piston assembly of FIG. 22;

FIG. 28c is a top view of an auxiliary shaft of the piston assembly of FIG. 22;

FIG. 29 is a cross-sectional side view of a zero-stroke coupling;

FIG. 29a is an exploded view of the zero-stroke coupling of FIG. 29;

FIG. 30 is a graph showing the figure 8 motion of a non-flat piston assembly;

FIG. 31 shows a reinforced drive pin;

FIG. 32 is a top view of a four cylinder engine for directly applying combustion pressures to pump pistons;

FIG. 32a is an end view of the four cylinder engine, taken along lines 32a, 32a of FIG. 32;

FIG. 33 is a cross-sectional top view of an alternative embodiment of a variable stroke assembly shown in a maximum stroke position;

FIG. 47 is a side view showing the coupling of a transition arm to a flywheel;

FIG. 48 is a side view of an alternative coupling of the transition arm to the flywheel;

FIG. 49 is a side view of an additional alternative coupling of the transition arm to the flywheel;

FIG. 50 is a cross-sectional side view of a hydraulic pump;

FIG. 51 is an end view of a face valve of the hydraulic pump of FIG. 50;

FIG. 52 is a cross-sectional view of the hydraulic pump of FIG. 30, taken along lines 52-52;

FIG. 53 is an end view of a face plate of the hydraulic pump of FIG. 50;

FIG. 54 is a partially cut-away side view of a variable compression piston assembly; and

FIG. 55 is a cross-sectional side view of the piston assembly of FIG. 54, taken along lines 55-55.

Description of the Preferred Embodiments

FIG. 1 is a pictorial representation of a four piston engine 10 of the present invention. Engine 10 has two cylinders 11 (FIG. 3) and 12. Each cylinder 11 and 12 house a double ended piston. Each double ended piston is connected to transition arm 13 which is connected to flywheel 15 by shaft 14. Transition arm 13 is connected to support 19 by a universal joint mechanism, including shaft 18, which allows transition arm 13 to move up an down and shaft 17 which allows transition arm 13 to move side to side. FIG. 1 shows flywheel 15 in a position shaft 14 at the top of wheel 15.

FIG. 2 shows engine 10 with flywheel 15 rotated so that shaft 14 is at the bottom of flywheel 15. Transition arm 13 has pivoted downward on shaft 18.

FIGS. 3-6 show a top view of the pictorial representation, showing the transition arm 13 in four positions and shaft moving flywheel 15 in 90° increments. FIG. 3 shows flywheel 15 with shaft 14 in the position as illustrated in FIG. 3a. When piston 1 fires and moves toward the middle of cylinder 11, transition arm 13

Exhaust manifolds 48 and 56 as shown attached to cylinders 46 and 31 respectively. Each exhaust manifold is attached to four exhaust ports.

FIG. 8 is a side view of engine 30, with one side removed, and taken through section 8-8 of FIG. 7. Transitions arm 60 is mounted on support 70 by pin 72 which allows transition arm to move up and down (as viewed in FIG. 8) and pin 71 which allows transition arm 60 to move from side to side. Since transition arm 60 can move up and down while moving side to side, then shaft 61 can drive flywheel 69 in a circular path. The four connecting piston arms (piston arms 54b and 54d, shown in FIG. 8) are driven by the four double end pistons in an oscillator motion around pin 71. The end of shaft 61 in flywheel 69 causes transition arm to move up and down as the connection arms move back and forth. Flywheel 69 has gear teeth 69a around one side which may be used for turning the flywheel with a starter motor 100 (FIG. 11) to start the engine.

The rotation of flywheel 69 and drive shaft 68 connected thereto, turns gear 65 which in turn turns gears 64 and 66. Gear 64 is attached to shaft 63 which turns pulley 50a. Pulley 50a is attached to belt 51. Belt 51 turns pulley 50b and gears 39 and 40 (FIG. 7). Cam shaft 75 has cams 88-91 on one end and cams 84-87 on the other end. Cams 88 and 90 actuate push rods 76 and 77, respectively. Cams 89 and 91 actuate push rods 93 and 94, respectively. Cams 84 and 86 actuate push rods 95 and 96, respectively, and cams 85 and 87 actuate push rods 78 and 79, respectively. Push rods 77, 76, 93, 94, 95, 96 and 78, 79 are for opening and closing the intake and exhaust valves of the cylinders above the pistons. The left side of the engine, which has been cutaway, contains an identical, but opposite valve drive mechanism.

Gear 66 turned by gear 65 on drive shaft 68 turns pump 67, which may be, for example, a water pump used in the engine cooling system (not illustrated), or an oil pump.

FIG. 9 is a rear view of engine 30 showing the relative positions of the cylinders and double ended pistons. Piston 32, 33 is shown in dashed lines with valves 35c and 35d located under lifter arms 35a and 35b, respectively. Belt 51 and

The piston arms on the transition arm are inserted into sleeve bearings in a bushing in piston. FIG. 14 shows a double piston 110 having piston rings 111 on one end of the double piston and piston rings 112 on the other end of the double piston. A slot 113 is in the side of the piston. The location the sleeve bearing is shown at 114.

FIG. 15 shows a piston arm 116 extending into piston 110 through slot 116 into sleeve bearing 117 in bushing 115. Piston arm 116 is shown in a second position at 116a. The two pistons arms 116 and 116a show the movement limits of piston arm 116 during operation of the engine.

FIG. 16 shows piston arm 116 in sleeve bearing 117. Sleeve bearing 117 is in pivot pin 115. Piston arm 116 can freely rotate in sleeve bearing 117 and the assembly of piston arm 116. Sleeve bearing 117 and pivot pin 115 and sleeve bearings 118a and 118b rotate in piston 110, and piston arm 116 can be moved axially with the axis of sleeve bearing 117 to allow for the linear motion of double ended piston 110, and the motion of a transition arm to which piston arm 116 is attached.

FIG. 17 shows how the four cylinder engine 10 in FIG. 1 may be configured as an air motor using a four way rotary valve 123 on the output shaft 122. Each of cylinders 1, 2, 3 and 4 are connected by hoses 131. 132, 133, and 144, respectively, to rotary valve 123. Air inlet port 124 is used to supply air to run engine 120. Air is sequentially supplied to each of the pistons 1a, 2a, 3a and 4a, to move the pistons back and forth in the cylinders. Air is exhausted from the cylinders out exhaust port 136. Transition arm 126, attached to the pistons by connecting pins 127 and 128 are moved as described with references to FIGS. 1-6 to turn flywheel 129 and output shaft 22.

FIG. 18 is a cross-sectional view of rotary valve 123 in the position when pressurized air or gas is being applied to cylinder 1 through inlet port 124, annular channel 125, channel 126, channel 130, and air hose 131. Rotary valve 123 is made up of a plurality of channels in housing 123 and output shaft 122. The pressurized air entering cylinder 1 causes piston 1a, 3a to move to the right (as viewed in FIG. 18).

be at an angle other than 90° to the drive arm 154. Even with the cylinders not parallel to each other the engines are functionally the same.

Still another modification may be made to the engine 10 of FIGS. 1-6. This embodiment, pictorially shown in FIG. 21, may have single ended pistons. Piston 1a and 2a are connected to universal joint 170 by drive arms 171 and 172, and to flywheel 173 by drive arm 174. The basic difference is the number of strokes of pistons 1a and 2a to rotate flywheel 173 360°.

Referring to FIG. 22, a two cylinder piston assembly 300 includes cylinders 302, 304, each housing a variable stroke, double ended piston 306, 308, respectively. Piston assembly 300 provides the same number of power strokes per revolution as a conventional four cylinder engine. Each double ended piston 306, 308 is connected to a transition arm 310 by a drive pin 312, 314, respectively. Transition arm 310 is mounted to a support 316 by, e.g., a universal joint 318 (U-joint), constant velocity joint, or spherical bearing. A drive arm 320 extending from transition arm 310 is connected to a rotatable member, e.g., flywheel 322.

Transition arm 310 transmits linear motion of pistons 306, 308 to rotary motion of flywheel 322. The axis, A, of flywheel 322 is parallel to the axes, B and C, of pistons 306, 308 (though axis, A, could be off-axis as shown in FIG. 20) to form an axial or barrel type engine, pump, or compressor. U-joint 318 is centered on axis, A. As shown in FIG. 28a, pistons 306, 308 are 180? apart with axes A, B and C lying along a common plane, D, to form a flat piston assembly.

Referring to FIGS. 22 and 23, cylinders 302, 304 each include left and right cylinder halves 301a, 301b mounted to the assembly case structure 303. Double ended pistons 306, 308 each include two pistons 330 and 332, 330a and 332a, respectively, joined by a central joint 334, 334a, respectively. The pistons are shown having equal length, though other lengths are contemplated. For example, joint 334 can be off-center such that piston 330 is longer than piston 332. As the pistons are fired in sequence 330a, 332, 330, 332a, from the position shown in FIG. 22, flywheel 322 is rotated in a clockwise direction, as viewed in the direction of arrow 333.

between joint 934 and pistons 330, 332 only produces a force vector which is parallel to piston axis, B (which is orthogonal to axes M and N).

Sliding movement along axis, M, accommodates the change in the radial distance of transition arm 310 to the center line, B, of the piston with the angle of swing, α, of transition arm 310. Sliding movement along axis, N, allows for the additional freedom of motion required to prevent binding of the pistons as they undergo the figure eight motion, discussed below. Joint 934 defines two opposed flat faces 937, 937a which slide in the directions of axes M and N relative to pistons 330, 332. Faces 937, 937a define parallel planes which remain perpendicular to piston axis, B, during the back and forth movement of the pistons.

Joint 934 includes an outer slider member 935 which defines faces 937, 937a for receiving the driving force from pistons 330, 332. Slider member 935 defines a slot 940 in a third face 945 of the slider for receiving drive pin 312, and a slot 940a in a fourth face 945a. Slider member 935 has an inner wall 936 defining a hole 939 perpendicular to slot 940 and housing a slider sleeve bearing 938. A cross shaft 941 is positioned within sleeve bearing 938 for rotation within the sleeve bearing in the direction of arrow 909. Sleeve bearing 938 defines a side slot 942 shaped like slot 940 and aligned with slot 940. Cross shaft 941 defines a through hole 944. Drive pin 312 is received within slot 942 and hole 944. A sleeve bearing 946 is located in through hole 944 of cross shaft 941.

The combination of slots 940 and 942 and sleeve bearing 938 permit drive pin 312 to move in the direction of arrow 909. Positioned within slot 940a is a cap screw 947 and washer 949 which attach to drive pin 312 retaining drive pin 312 against a step 951 defined by cross shaft 941 while permitting drive pin 312 to rotate about its axis, E, and preventing drive pin 312 from sliding along axis, E. As discussed above, the two addition freedoms of motion are provided by sliding of slider faces 937, 937a relative to pistons 330, 332 along axis, M and N. A plate 960 is placed between each of face 937 and piston 330 and face 937a and piston 332. Each plate 960 is formed of a low friction bearing material with a bearing surface 962 in contact with faces 937, 937a, respectively. Faces 937, 937a are polished.

Referring to FIGS. 24 and 24a, U-joint 318 defines a central pivot 352 (drive pin axis, E, passes through center 352), and includes a vertical pin 354 and a horizontal pin 356. Transition arm 310 is capable of pivoting about pin 354 along arrow 358, and about pin 356 along arrow 360.

Referring to FIGS. 25, 25a and 25b, as an alternative to a spherical bearing, to couple transition arm 310 to flywheel 322, drive arm 320 is received within a cylindrical pivot pin 370 mounted to the flywheel offset radially from the center 372 of the flywheel by an amount, e.g., 2.125 inches, required to produce the desired swing angle, α (FIG. 22), in the transition arm.

Pivot pin 370 has a through hole 374 for receiving drive arm 320. There is a sleeve bearing 376 in hole 374 to provide a bearing surface for drive arm 320. Pivot pin 370 has cylindrical extensions 378, 380 positioned within sleeve bearings 382, 384, respectively. As the flywheel is moved axially along drive arm 320 to vary the swing angle, α. and thus the compression ratio of the assembly, as described further below, pivot pin 370 rotates within sleeve bearings 382, 384 to remain aligned with drive arm 320. Torsional forces are transmitted through thrust bearings 388, 390, with one or the other of the thrust bearings carrying the load depending on the direction of the rotation of the flywheel along arrow 386.

Referring to FIG. 26, to vary the compression and displacement of piston assembly 300, the axial position of flywheel 322 along axis, A, is varied by rotating a shaft 400. A sprocket 410 is mounted to shaft 400 to rotate with shaft 400. A second sprocket 412 is connected to sprocket 410 by a roller chain 413. Sprocket 412 is mounted to a threaded rotating barrel 414. Threads 416 of barrel 414 contact threads 418 of a stationary outer barrel 420.

Rotation of shaft 400, arrow 401, and thus sprockets 410 and 412, causes rotation of barrel 414. Because outer barrel 420 is fixed, the rotation of barrel 414 causes barrel 414 to move linearly along axis, A, arrow 403. Barrel 414 is positioned between a collar 422 and a gear 424, both fixed to a main drive shaft 408. Drive shaft 408 is in turn fixed to flywheel 322. Thus, movement of barrel 414 along axis, A, is translated to linear movement of flywheel 322 along axis, A. This results in

408 and the interface of drive arm 320 with flywheel 322 are lubricated via ports 433 (Fig. 26).

Referring to FIG. 27, to lubricate U-joint 318, piston pin joints 306, 308, and the cylinder walls, oil under pressure from the oil pump is ported through the fixed U-joint bracket to the top and bottom ends of the vertical pivot pin 354. Oil ports 450, 452 lead from the vertical pin to openings 454, 456, respectively, in the transition arm. As shown in FIG. 27A, pins 312, 314 each define a through bore 458. Each through bore 458 is in fluid communication with a respective one of openings 454, 456. As shown in FIG. 23, holes 460, 462 in each pin connect through slots 461 and ports 463 through sleeve bearing 338 to a chamber 465 in each piston. Several oil lines 464 feed out from these chambers and are connected to the skirt 466 of each piston to provide lubrication to the cylinders walls and the piston rings 467. Also leading from chamber 465 is an orifice to squirt oil directly onto the inside of the top of each piston for cooling.

Referring to FIGS. 28-28c, in which assembly 300 is shown configured for use as an aircraft engine 300a, the engine ignition includes two magnetos 600 to fire the piston spark plugs (not shown). Magnetos 600 and a starter 602 are driven by drive gears 604 and 606 (FIG. 28c), respectively, located on a lower shaft 608 mounted parallel and below the main drive shaft 408. Shaft 608 extends the full length of the engine and is driven by gear 424 (Fig. 26) of drive shaft 408 and is geared with a one to one ratio to drive shaft 408. The gearing for the magnetos reduces their speed to half the speed of shaft 608. Starter 602 is geared to provide sufficient torque to start the engine.

Camshafts 610 operate piston push rods 612 through lifters 613. Camshafts 610 are geared down 2 to 1 through bevel gears 614, 616 also driven from shaft 608. Center 617 of gears 614, 616 is preferably aligned with U-joint center 352 such that the camshafts are centered in the piston cylinders, though other configurations are contemplated. A single carburetor 620 is located under the center of the engine with four induction pipes 622 routed to each of the four cylinder intake

The ability to vary the piston stroke permits shaft 514 to be run at a single speed by drive 532 while the output of the pump or compressor can be continually varied as needed. When no output is needed, pivot arm 504 simply spins around drive arm 320 of transition arm 310 with zero swing of the drive arm. When output is needed, shaft 514 is already running at full speed so that when pivot arm 504 is pulled off-axis by control rod 514, an immediate stroke is produced with no lag coming up to speed. There are therefore much lower stress loads on the drive system as there are no start/stop actions. The ability to quickly reduce the stroke to zero provides protection from damage especially in liquid pumping when a downstream blockage occurs.

An alternative method of varying the compression and displacement of the pistons is shown in FIG. 33. The mechanism provides for varying of the position of a counterweight attached to the flywheel to maintain system balance as the stroke of the pistons is varied.

A flywheel 722 is pivotally mounted to an extension 706 of a main drive shaft 708 by a pin 712. By pivoting flywheel 722 in the direction of arrow, Z, flywheel 722 slides along axis, H, of a drive arm 720 of transition arm 710, changing angle, β (Fig. 26), and thus the stroke of the pistons. Pivoting flywheel 722 also causes a counterweight 714 to move closer to or further from axis, A, thus maintaining near rotational balance.

To pivot flywheel 722, an axially and rotationally movable pressure plate 820 is provided. Pressure plate 820 is in contact with a roller 822 rotationally mounted to counterweight 714 through a pin 824 and bearing 826. From the position shown in FIG. 33, a servo motor or hand knob 830 turns a screw 832 which advances to move pressure plate 820 in the direction of arrow, Y. This motion of pressure plate 820 causes flywheel 722 to pivot in the direction of arrow, Z, as shown in the FIG. 34, to decrease the stroke of the pistons. Moving pressure plate 820 by 0.75" decreases the compression ratio from about 12:1 to about 6:1.

Pressure plate 820 is supported by three or more screws 832. Each screw has a gear head 840 which interfaces with a gear 842 on pressure plate 820 such that

pump piston 604 is attached to the output side 606 of a corresponding piston cylinder 608. Pump pistons 604 extend into a pump head 610.

A transition arm 620 is connected to each cylinder 608 and to a flywheel 622, as described above. An auxiliary output shaft 624 is connected to flywheel 622 to rotate with the flywheel, also as described above.

The engine is a two stroke cycle engine because every stroke of a piston 602 (as piston 602 travels to the right as viewed in FIG. 32) must be a power stroke. The number of engine cylinders is selected as required by the pump. The pump can be a fluid or gas pump. In use as a multi-stage air compressor, each pump piston 606 can be a different diameter. No bearing loads are generated by the pumping function (for single acting pump compressor cylinders), and therefore, no friction is introduced other than that generated by the pump pistons themselves.

Referring to FIGS. 38-38B, an engine 1010 having vibration canceling characteristics and being particularly suited for use in gas compression includes two assemblies 1012, 1014 mounted back-to-back and 180° out of phase. Engine 1010 includes a central engine section 1016 and outer compressor sections 1018, 1020. Engine section 1016 includes, e.g., six double acting cylinders 1022, each housing a pair of piston 1024, 1026. A power stroke occurs when a center section 1028 of cylinder 1022 is fired, moving pistons 1024, 1026 away from each other. The opposed movement of the pistons results in vibration canceling.

Outer compression section 1018 includes two compressor cylinders 1030 and outer compression section 1020 includes two compressor cylinders 1032, though there could be up to six compressor cylinders in each compression section. Compression cylinders 1030 each house a compression piston 1034 mounted to one of pistons 1024 by a rod 1036, and compression cylinders 1032 each house a compression piston 1038 mounted to one of pistons 1026 by a rod 1040. Compression cylinders 1030, 1032 are mounted to opposite piston pairs such that the forces cancel minimizing vibration forces which would otherwise be transmitted into mounting 1041.

opposite direction to the direction of rotation of gear 1110. The rotation of gear 1112 causes rotation of shaft 608 and thus rotation of counterweight 1116.

As viewed from the left in FIG. 39, counterweight 1114 rotates clockwise (arrow 1118) and counterweight 1116 rotates counterclockwise (arrow 1120). Counterweights 1114 and 1116 are mounted 180 degrees out of phase such that when counterweight 1114 is above shaft 408, counterweight 1116 is below shaft 608. A quarter turn results in both counterweights 1114, 1116 being to the right of their respective shafts (see FIG. 40). After another quarter turn, counterweight 1114 is below shaft 408 and counterweight 1116 is above shaft 608. Another quarter turn and both counterweights are to the left of their respective shafts.

Referring to FIG. 40, movement of pistons 306, 308 along the Y axis, in the plane of the XY axes, creates a moment about the Z axis, M_{zy}. When counterweights 1114, 1116 are positioned as shown in FIG. 40, the centrifugal forces due to their rotation creates forces, F_{x1} and F_{x2}, respectively, parallel to the X axis. These forces act together to create a moment about the Z axis, M_{zx}. The weight of counterweights 1114, 1116 is selected such that M_{zx} substantially cancels M_{zy}.

When pistons 306, 308 are centered on the X axis (FIG. 39) there are no forces acting on pistons 306, 308, and thus no moment about the Z axis. In this position, counterweights 1114, 1116 are in opposite positions as shown in FIG. 39 and the moments created about the X axis by the centrifugal forces on the counterweights cancel. The same is true after 180 degrees of rotation of shafts 408 and 608, when the pistons are again centered on the X axis and the counterweight 1114 is below shaft 408 and counterweight 1116 is above shaft 608.

Between the quarter positions, the moments about the X axis due to rotation of counterweights 1114 and 1116 cancel, and the moments about the Z axis due to rotation of counterweights 1114 and 1116 add.

Counterweight 1114 also accounts for moments produced by drive arm 320.

In other piston configurations, for example where pistons 306, 308 do not lie on a common plane or where there are more than two pistons, counterweight 1116

Between the quarter positions, the moments about the X axis due to rotation of counterweights 1130 and 1132 cancel, and the moments about the Z axis due to rotation of counterweights 1130 and 1132 add. Since counterweights 1130 and 1132 both rotate about the Y axis, there is no moment M_{yx} created about axis Y.

Counterweights 1130, 1132 are positioned close together along the Y axis to provide near equal moments about the Z axis. The weights of counterweights 1130, 1132 can be slightly different to account for their varying location along the Y axis so that each counterweight generates the same moment about the center of gravity of the engine.

Counterweights 1130, 1132, in addition to providing the desired moments about the Z axis, create undesirable lateral forces directed perpendicular to the Y-axis (in the direction of the X aixs), which act on the U-joint or other mount supporting transition arm 310. When counterweights 1130, 1132 are positioned as shown in FIG. 41, this does not occur because the upward force, F_u, and the downward force, F_d, cancel. But, when counterweights 1130, 1132 are positioned other than as shown in FIG. 41 or 180° from that position, this force is applied to the mount. For example, as shown in FIG. 42, forces F_{x3} and F_{x4} create a side force, F_s, along the X axis. One technique of incorporating counterbalances which provide the desired moments about the Z axis without creating the undesirable forces on the mount is shown in FIG. 43.

Referring to FIG. 43, a second pair of counterweights 1150, 1152 are provided. Counterweights 1130 and 1152 are mounted to shaft 408 to rotate clockwise with shaft 408. Counterweights 1132 and 1150 are mounted to a cylinder 1154 surrounding shaft 408 which is driven through pulley system 1134 to rotate counterclockwise. Counterweights 1130, 1152 extend from opposite sides of shaft 408 (counterweight 1130 being directed downward in Fig. 43, and counterweight 1152 being directed upward), and counterweights 1132, 1150 extend from opposite sides of cylinder 1154 (counterweight 1132 being directed upward, and counterweight 1150 being directed downward). Counterweights 1130, 1150 are

counterweights 1164, 1166. Members 1160, 1162 are 180° apart and equally spaced between pistons 306, 308. Counterweights 1164, 1166 extend from opposite sides of shaft 408, with counterweight 1166 being spaced further from the Z axis than counterweight 1164. Here again, counterweight 1114a mounted to rotating member 1108 is sized to only balance transition arm 310.

Movement of members 1160, 1162 along the Y axis, in the plane of the YZ axis, creates a moment about the X axis, M_{xy}. When counterweights 1164, 1166 are positioned as shown in FIG. 45, the centrifugal forces due to the rotation of counterweights 1164, 1166 creates forces, F_u and F_d, respectively, in opposite directions along the Z axis. Since counterweight 1166 is located further from the Z axis than counterweight 1164, the moment created by counterweight 1166 is larger than the moment created by counterweight 1164 such that these forces act together to create a moment about the X axis, M_{xz}, which acts in the opposite direction to M_{xy}. The weight of counterweights 1164, 1166 is selected such that M_{xz} substantially cancels M_{xy}.

In addition, since the forces, F_u and F_d, are oppositely directed, these forces cancel such that no undesirable lateral forces are applied to the transition arm mount.

Referring to FIG. 46, movement of pistons 306, 308 along the Y axis, in the plane of the XY axes, creates a moment about the Z axis, M_{zy}. When counterweights 1164, 1166 are positioned as shown in FIG. 45, the centrifugal forces due to the rotation of counterweights 1164, 1166 creates forces, F_{x7} and F_{x8}, respectively, in opposite directions along the X axis. These forces act together to create a moment about the Z axis, M_{zx}, which acts in the opposite direction to M_{zy}. The weight of counterweights 1164, 1166 is selected such that M_{zx} substantially cancels M_{zy}.

In addition, since the forces perpendicular to Y axis, F_{x7} and F_{x8}, are oppositely directed, these forces cancel such that no undesirable lateral forces are applied to the transition arm mount.

is received within a sleeve bearing 2024 in a cylindrical opening 2026 defined by flywheel 1108b. Because of the spherical shapes, no lateral thrust is produced by the centrifugal force, C_1.

Counterbalance element 2014 is not rigidly held to flywheel 1108b so that there is no restraint to the full force of the counterweight being applied to the spherical joint to cancel the centrifugal force created by the circular travel of transition arm 310. For example, a clearance space 2030 is provided in the screw holes 2032 defined in counterbalance element 2014 for receiving bolts 2016.

One advantage of this embodiment over that of FIG. 48 is that the life expectancy of a cylindrical joint with a sleeve bearing coupling the transition arm to the flywheel is longer than that of the spherical joint of FIG. 48 coupling the transition arm to the flywheel.

Referring to FIG. 50, a hydraulic pump 2110 includes a stationary housing 2112 defining a chamber 2114, and a rotating drum or cylinder 2116 located within chamber 2114. Cylinder 2116 includes first and second halves 2116a, 2116b defining a plurality of piston cavities 2117. Each cavity 2117 is formed by a pair of aligned channels 2118, 2120 joined by an enlarged region 2122 defined between cylinder halves 2116a, 2116b. Located within each cavity 2117 is a double ended piston 2124, here six pistons being shown, though fewer or more pistons can be employed depending upon the application. Each double ended piston is mounted to a transition arm 2126 by a joint 2128, as described above. Transition arm 2126 is supported on a universal joint 2130 mounted to cylinder 2116 such that pistons 2124 and transition arm 2126 rotate with cylinder 2116.

The angle, γ, of transition arm 2126 relative to longitudinal axis, A, of pump 2110 is adjustable to reduce or increase the output from pump 2110. Pump 2110 includes an adjustment mechanism 2140 for adjusting and setting angle, γ. Adjustment mechanism 2140 includes an arm 2142 mounted to a stationary support 2144 to pivot about a point 2146. An end 2148 of arm 2142 is coupled to a first end 2152 of a control rod 2150 by a pin 2154. Arm 2142 defines an elongated hole 2155 which receives pin 2154 and allows for radial movement of arm 2142 relative to

Referring also to FIG. 52, cylinder 2116 defines six flow channels 2180 through which fluid travels to and from channels 2120. Flow channels 2180 are radially aligned with port sections 2174a and 2178b; and channels 2118 are radially aligned with port sections 2174b and 2178b. When a first end 2124a of piston 2124 is on the intake stroke and a second end 2124b of piston 2124 is on the pump stroke, cylinder 2116 is rotationally aligned relative to stationary face valve 2170 such that the respective channel 2118 at first end 2124a of piston 2124 is aligned with inlet port section 2174b, and the respective flow channel 2180 leading to a respective channel 2120 at second end 2124b of piston 2124 is aligned with outlet port section 2178a.

Cylinder 2116 further defines six holes 2182 for receiving connecting bolts (not shown) that hold the two halves 2116a, 2116b of cylinder 2116 together. Cylinder 2116 is biased toward face valve 2170 to maintain a valve seal by spring loading. Referring to FIG. 53, a face plate 2190 defining outer slots 2192a and inner slots 2192b is positioned between stationary face valve 2170 and rotating cylinder 2116 to act as a bearing surface. Outer slots 2192a are radially aligned with port sections 2174a and 2178a, and inner slots 2192b are radially aligned with port sections 2174b and 2178b.

Referring to FIG. 54, a pump or compressor assembly 2210 for varying the stroke of pistons 2212, e.g., a pump with single ended pistons having a piston 2212a at one end and a guide rod 2212b at the opposite end, has the ability to vary the stroke of pistons 2212 down to zero stroke and the capability of handling torque loads as high as a fixed stroke mechanism. Assembly 2210 is shown with three pistons, though two or more pistons can be employed. Assembly 2210 includes a transition arm 2214 coupled to pistons 2212 by any of the methods described above. Transition arm 2214 includes a nose pin 2216 coupled to a rotatable flywheel 2218. The rotation of flywheel 2218 and the linear movement of pistons 2212 are coupled by transition arm 2214 as described above.

The stroke of pistons 2212, and thus the output volume of assembly 2210, is adjusted by changing the angle, δ, of nose pin 2216 relative to assembly axis, A.

1. A hydraulic pump, comprising:

a housing,

at least two pistons mounted to the housing to rotate relative to the housing, and

a transition arm coupled to each of the at least two pistons to rotate therewith.

2. The hydraulic pump of claim 1 wherein the at least two pistons are double ended pistons.

3. The hydraulic pump of claim 2 wherein each double ended piston has a first end and a second end and the transition arm is coupled to each of the double ended pistons between the first and second ends.

4. The hydraulic pump of claim 1 wherein the transition arm is set at a predetermined angle relative to a longitudinal axis of the pump.

5. The hydraulic pump of claim 1 further comprising an adjustment mechanism for setting the transition arm at a predetermined angle.

6. The hydraulic pump of claim 5 wherein the adjustment mechanism comprises first and second meshing gears.

7. The hydraulic pump of claim 6 wherein the first and second meshing gears are configured such that linear movement of the first gear causes rotary movement of the second gear, the second gear being coupled to the transition arm such that rotary movement of the second gear adjusts the predetermined angle of the transition arm.

8. The hydraulic pump of claim 1 further comprising a cylinder mounted within the housing to rotate relative to the housing and defining pump cavities for receiving the at least two pistons.

16. The hydraulic pump of claim 15 wherein the first and second joints are each configured to provide at least three degrees of freedom.

17. The hydraulic pump of claim 1 further comprising a universal joint supporting the transition arm.

18. The hydraulic pump of claim 17 wherein the universal joint is configured to rotate with the transition arm.

19. An apparatus for varying the output volume of a piston assembly, comprising:

at least two pistons,

a transition arm coupled to each of the at least two pistons, the transition arm including a nose pin, and

a rotatable member coupled to the transition arm nose pin, a radial position of the nose pin relative to an axis of rotation of the rotatable member being adjustable while the rotatable member remains axially stationary.

20. The apparatus of claim 19 wherein the rotatable member defines a channel for receiving the nose pin.

21. The apparatus of claim 20 further comprising a bearing block configured to slide within the channel.

22. The apparatus of claim 21 wherein the channel is arc shaped such that bearing block slides along a circumference of a circle.

23. The apparatus of claim 21 further comprising a bearing mounted in the bearing block for receiving the nose pin.

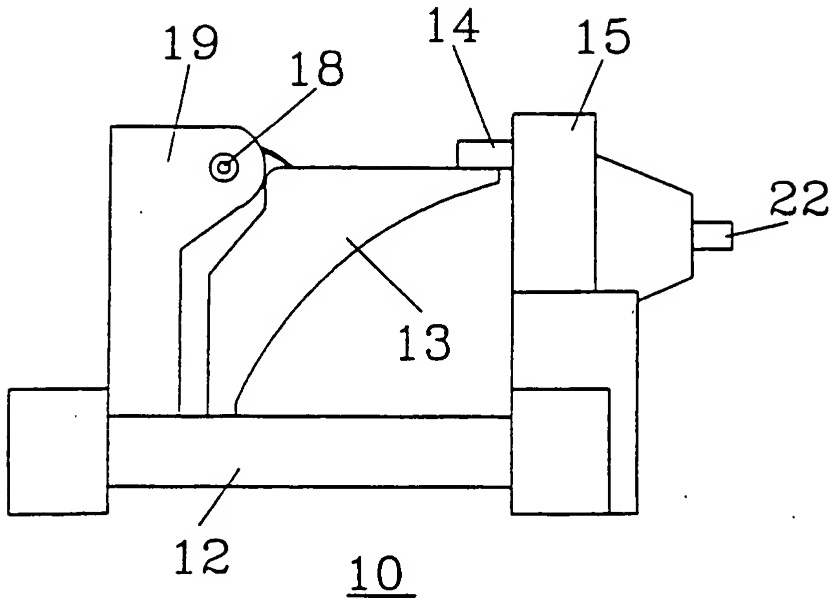


FIG. 1

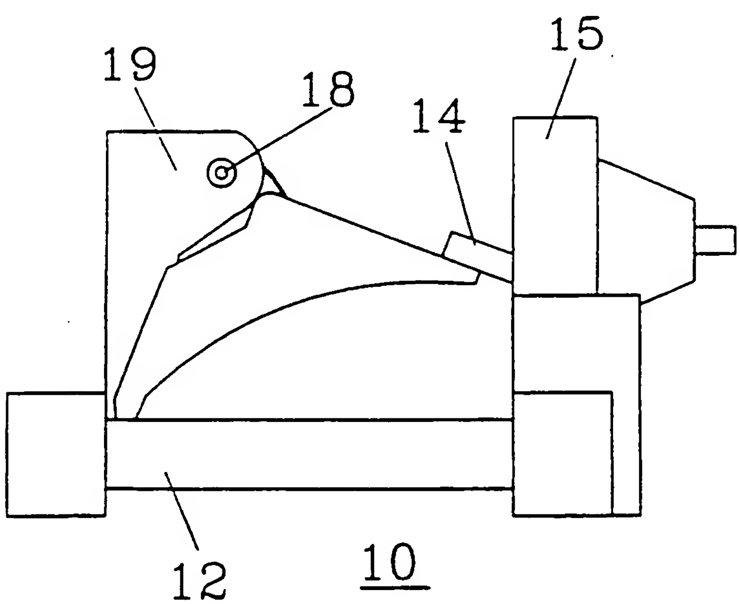
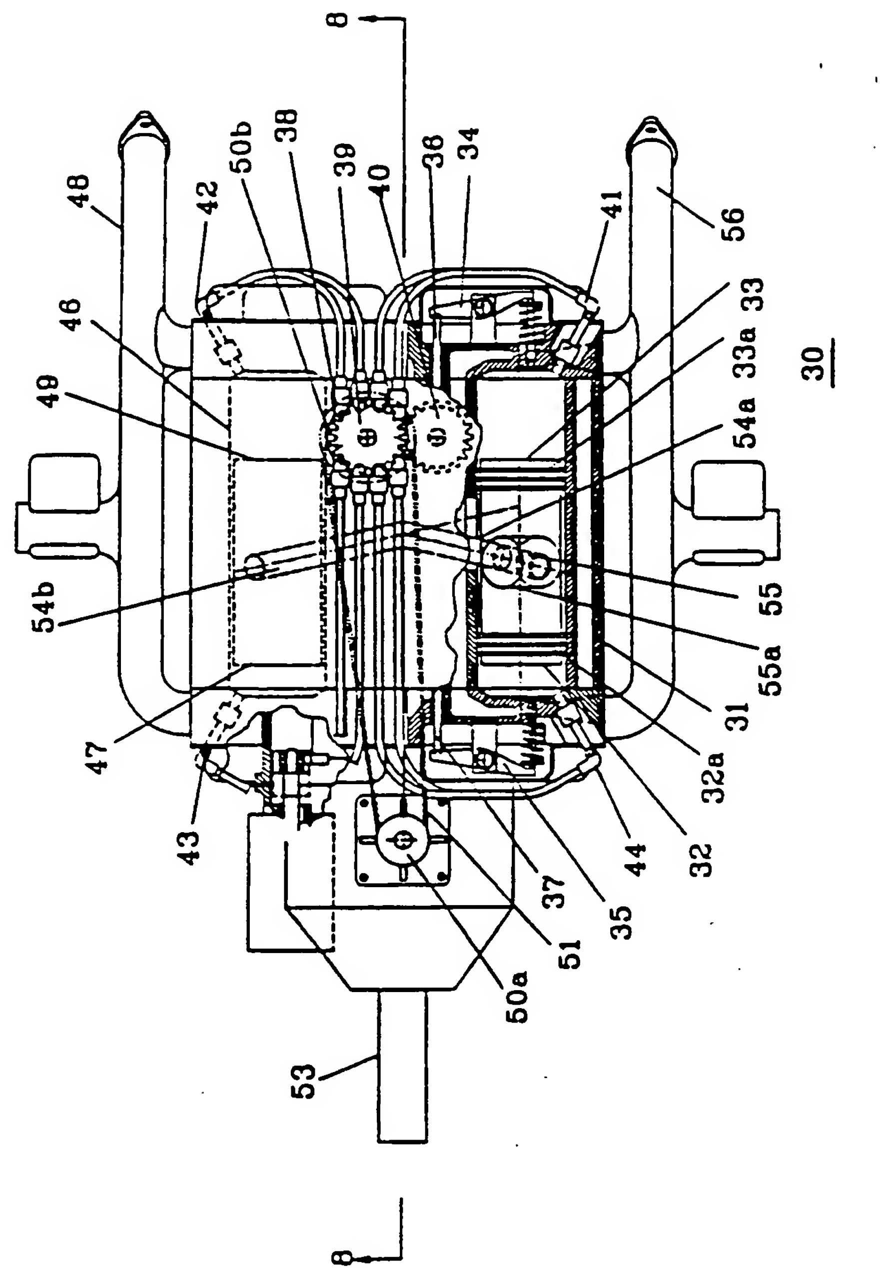


FIG. 2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50b
38
39
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36
34
41
56
33
33a
54a
30
46
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54b
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55a
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32a
32
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50a
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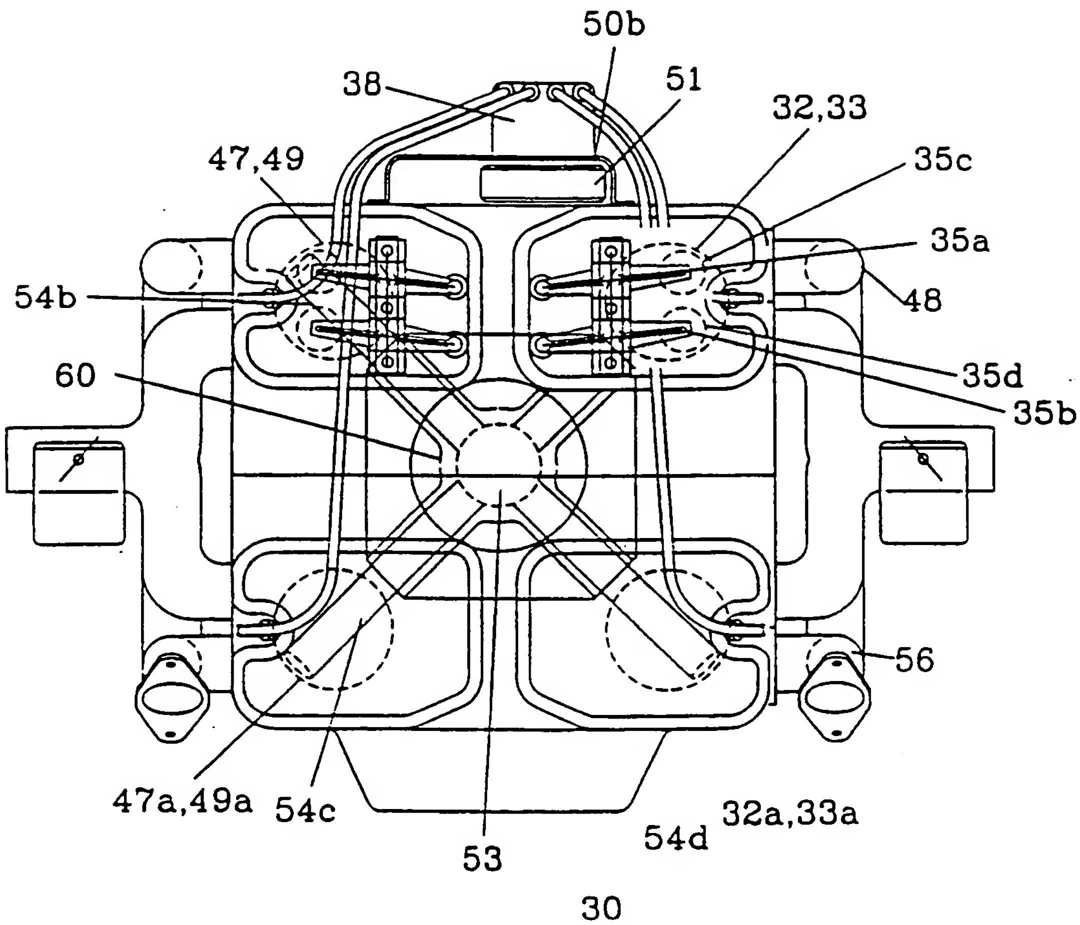
8

FIG. 7



50b
38
51
32,33
47,49
35c
35a
54b
48
60
35d
35b
56
47a,49a
54c
53
54d
32a,33a
30

FIG. 9

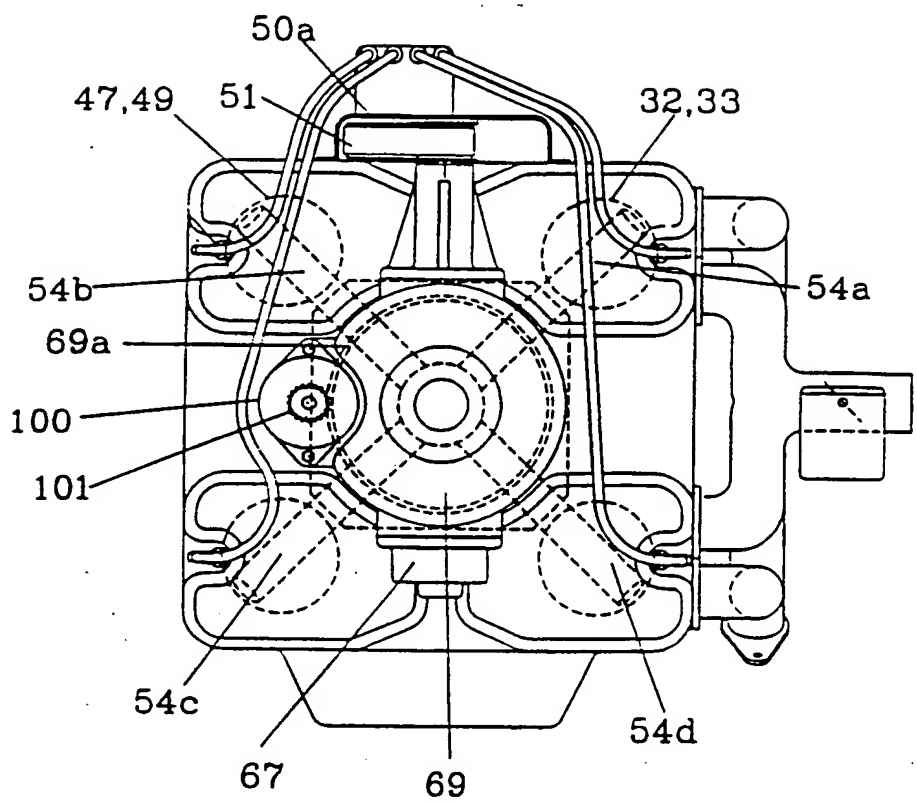


FIG. 11

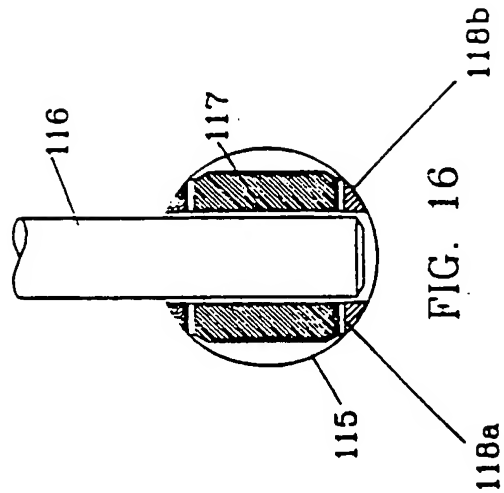


FIG. 16

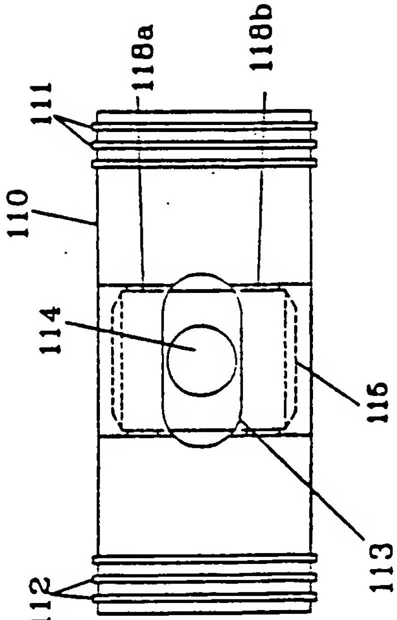


FIG. 14

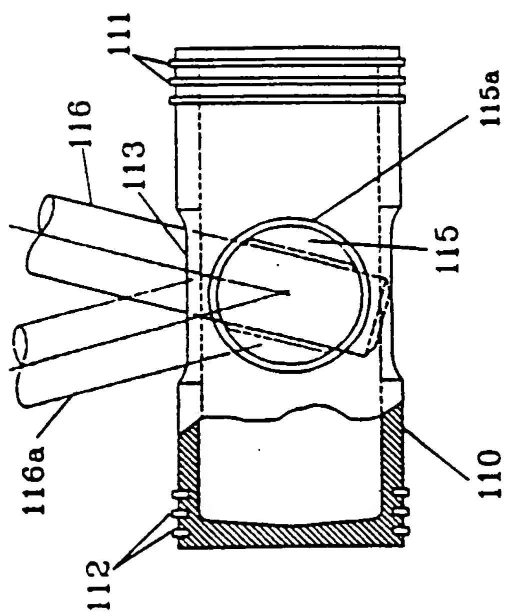


FIG. 15

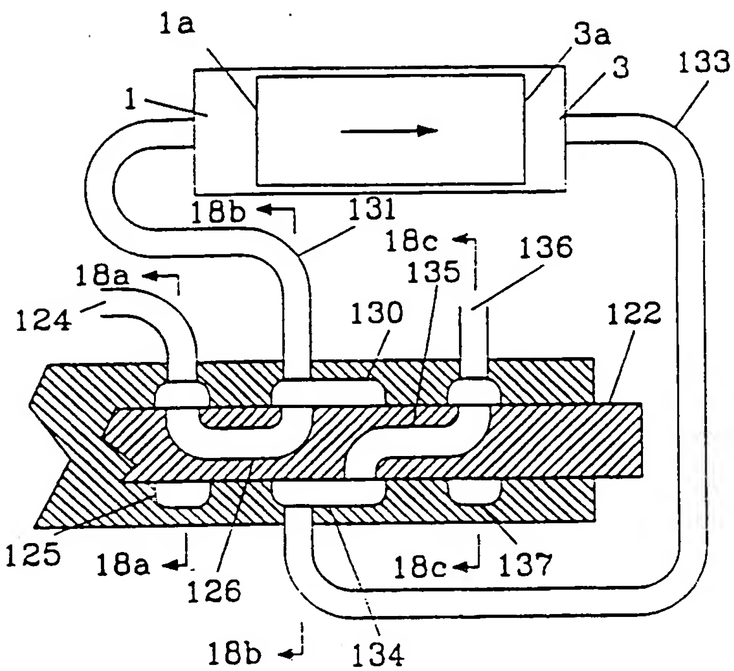


FIG. 18

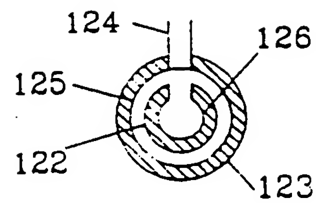


FIG. 18a

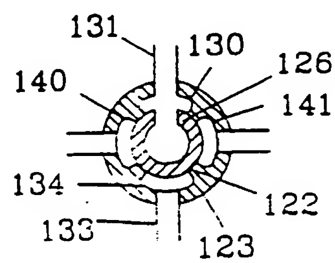


FIG. 18b

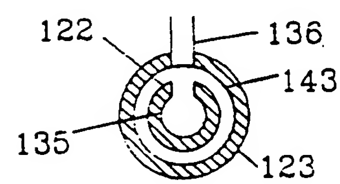


FIG. 18c

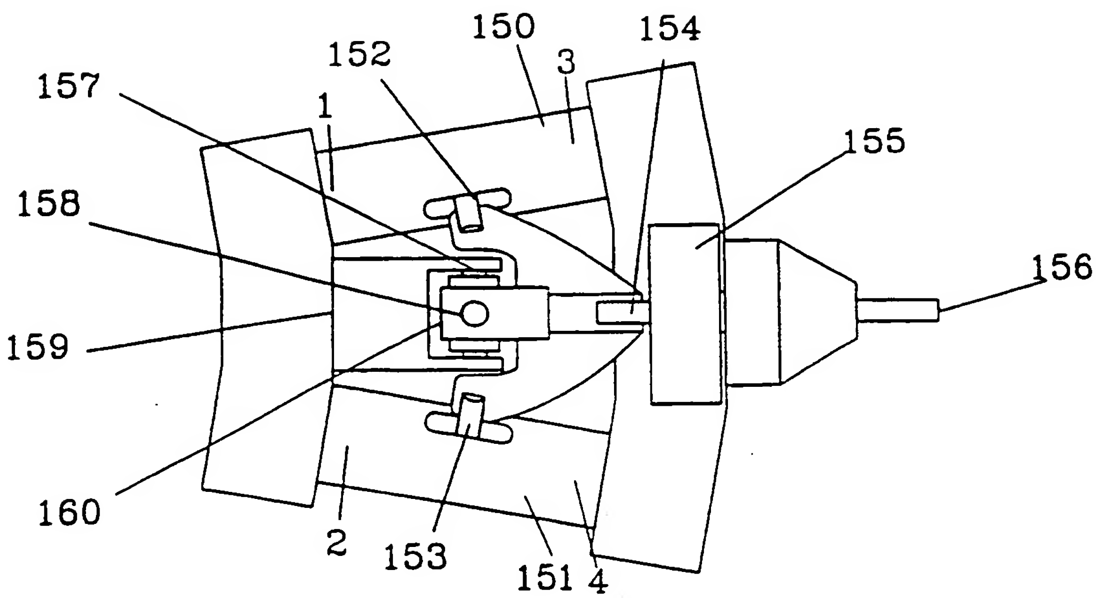
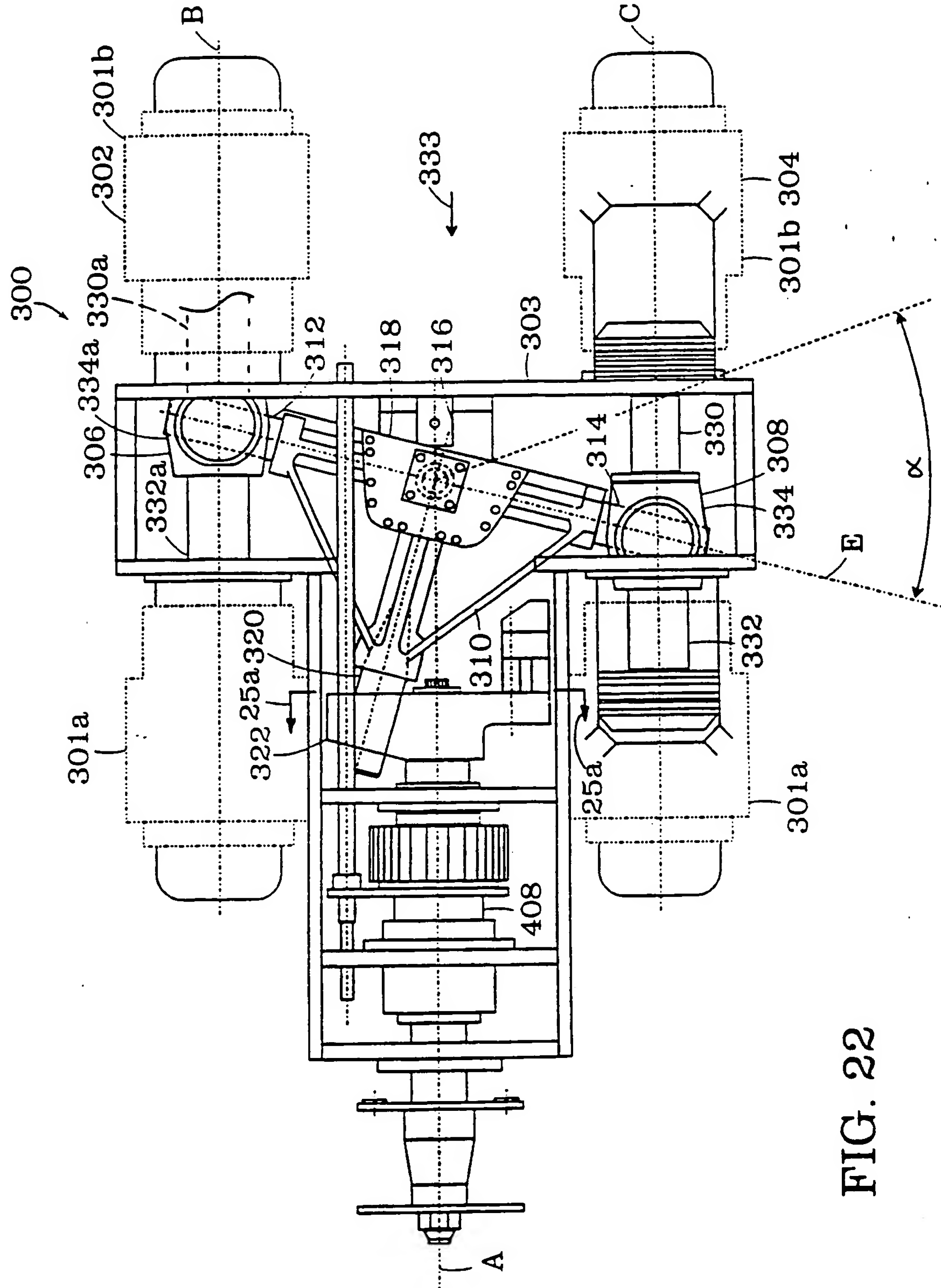


FIG. 20


B
C
301b
302
333
304
301b
300
330a
334a
312
318
316
303
306
332a
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330
308
334
E
α
320
25a
310
332
322
25a
301a
301a
408
A

FIG. 22

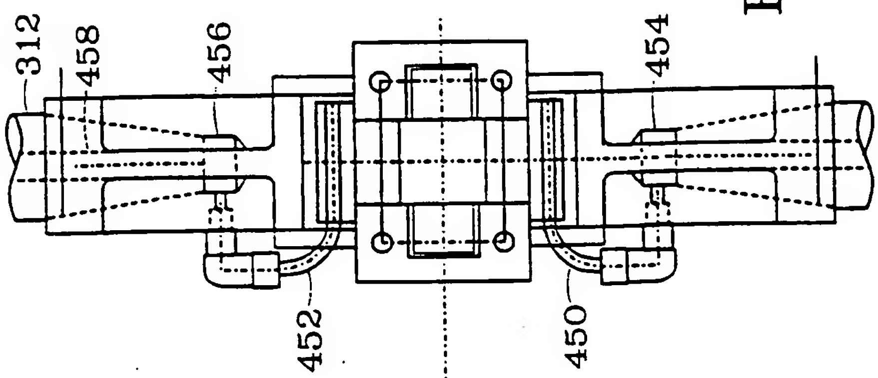


FIG. 27

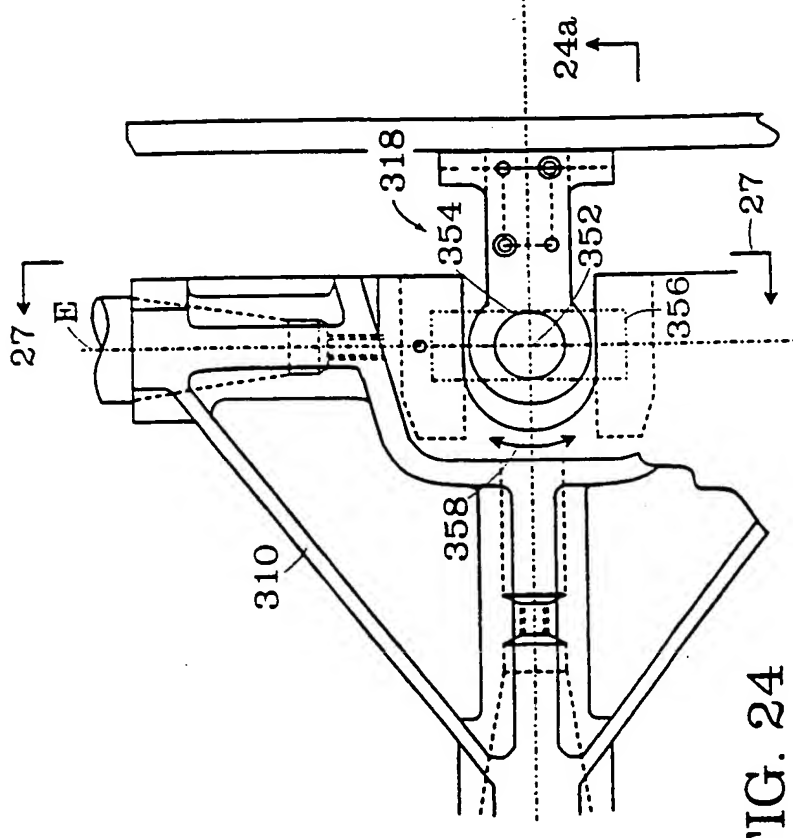


FIG. 24

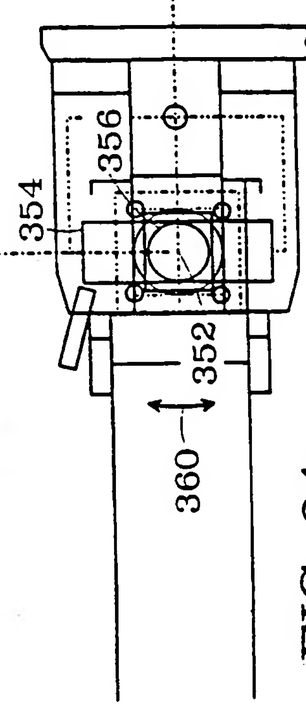


FIG. 24a

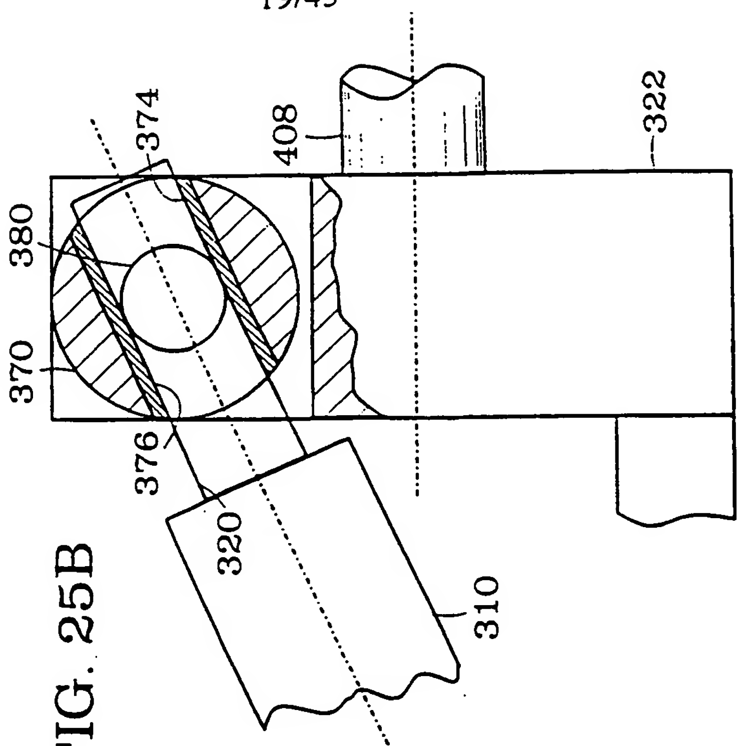


FIG. 25B

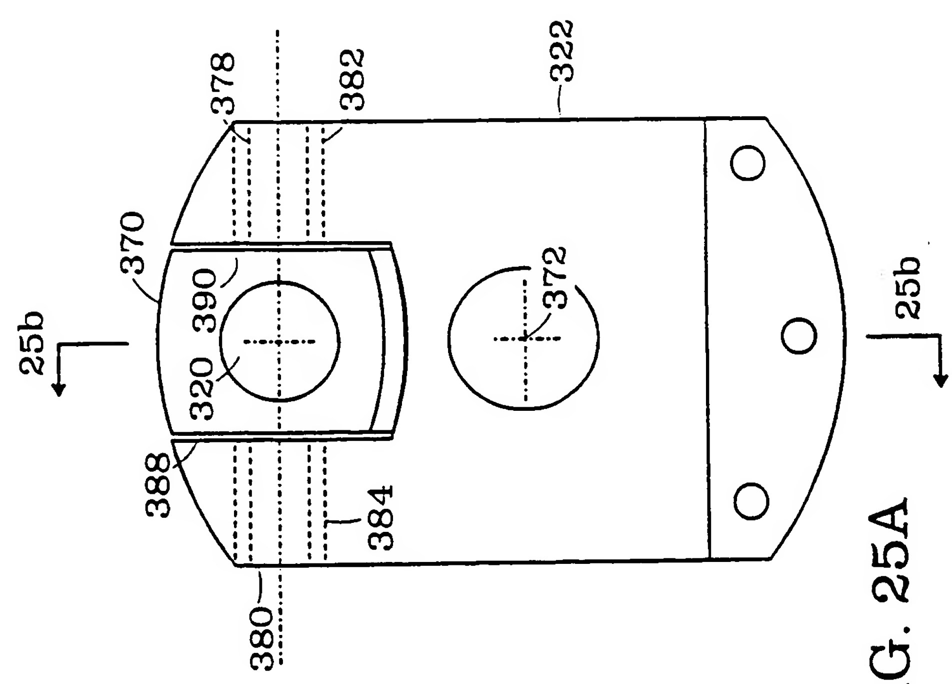


FIG. 25A

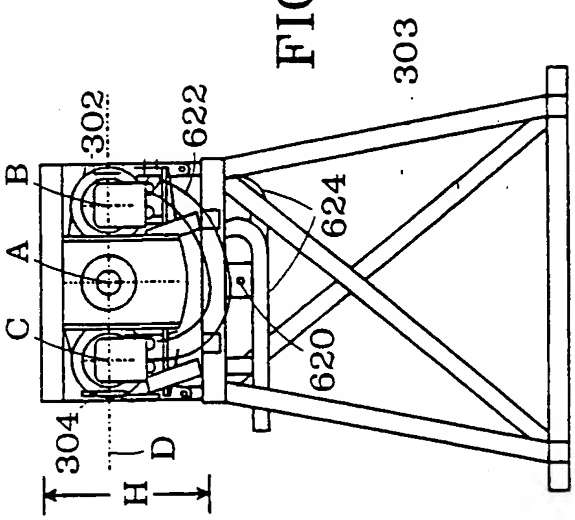


FIG. 28a

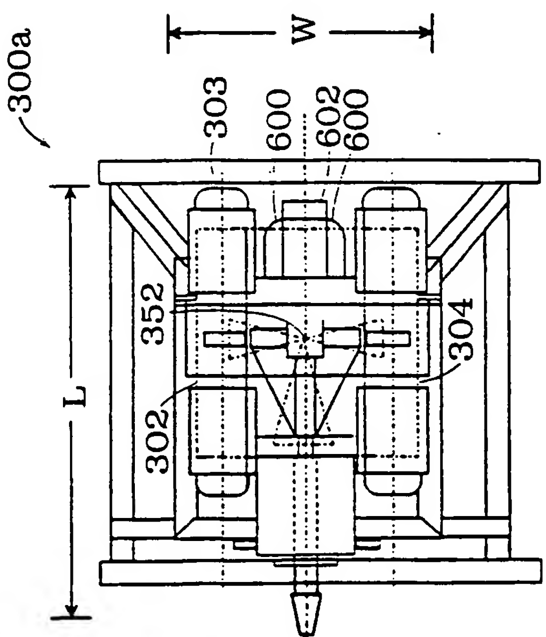


FIG. 28

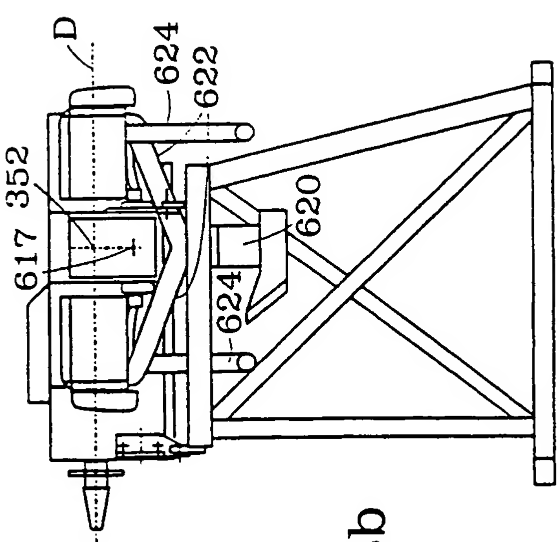


FIG. 28b

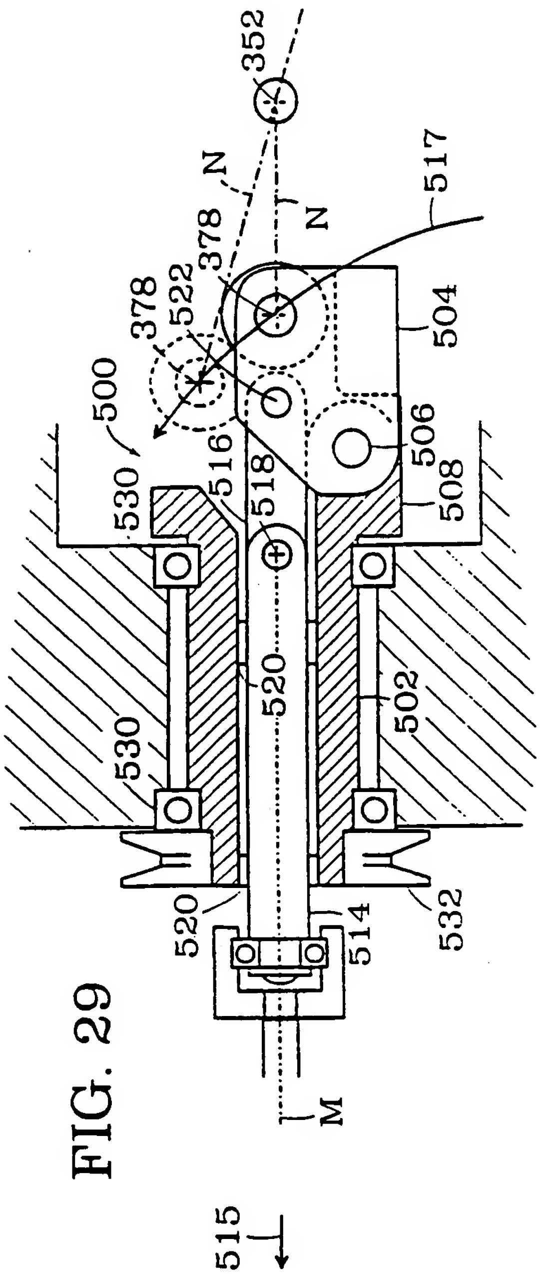


FIG. 29

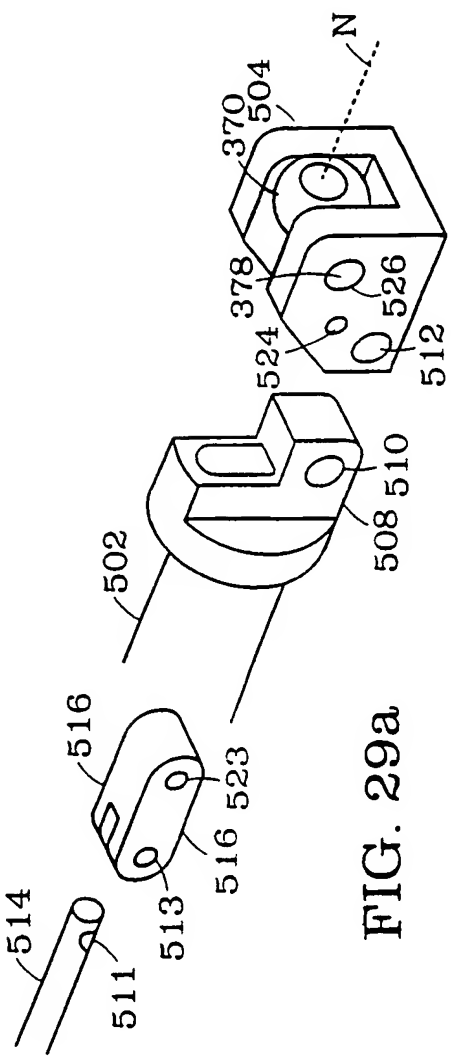


FIG. 29a

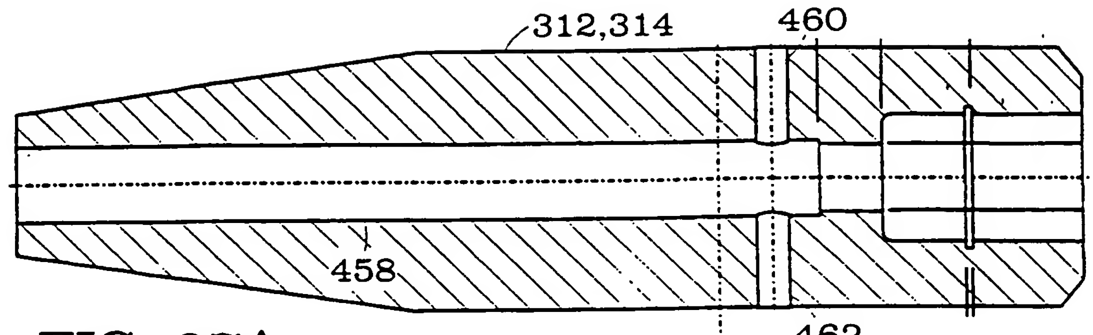


FIG. 27A

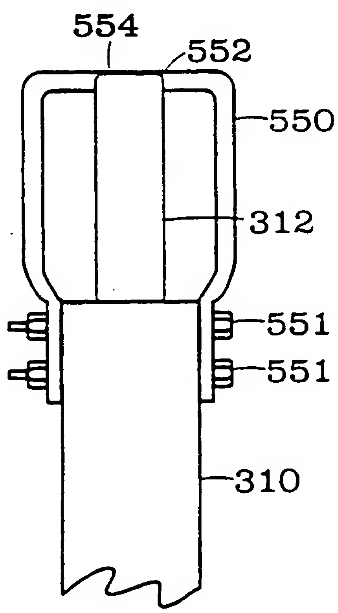
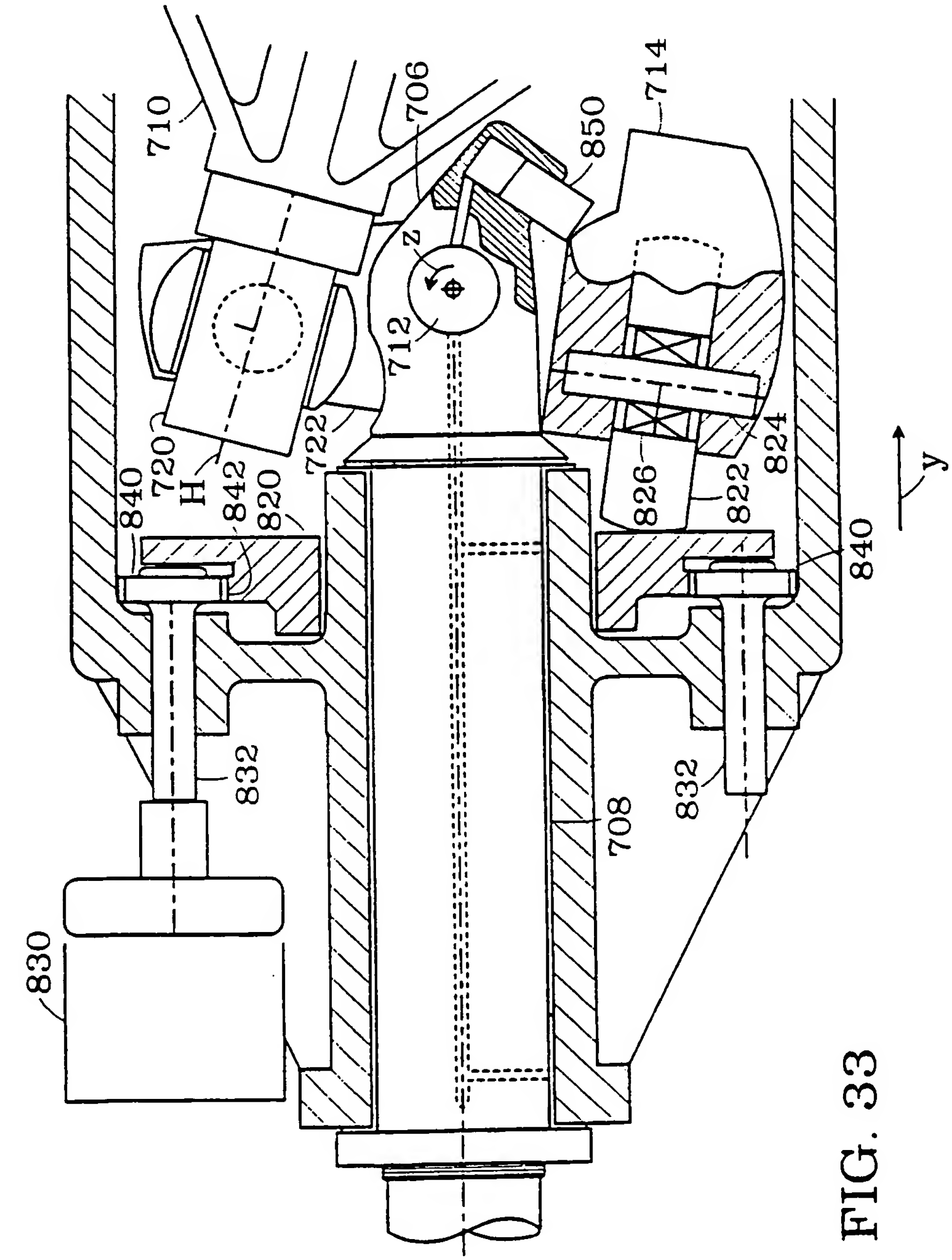


FIG. 31


710
706
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714
z
712
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H
842
820
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722
826
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824
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y
832
832
708
830

FIG. 33

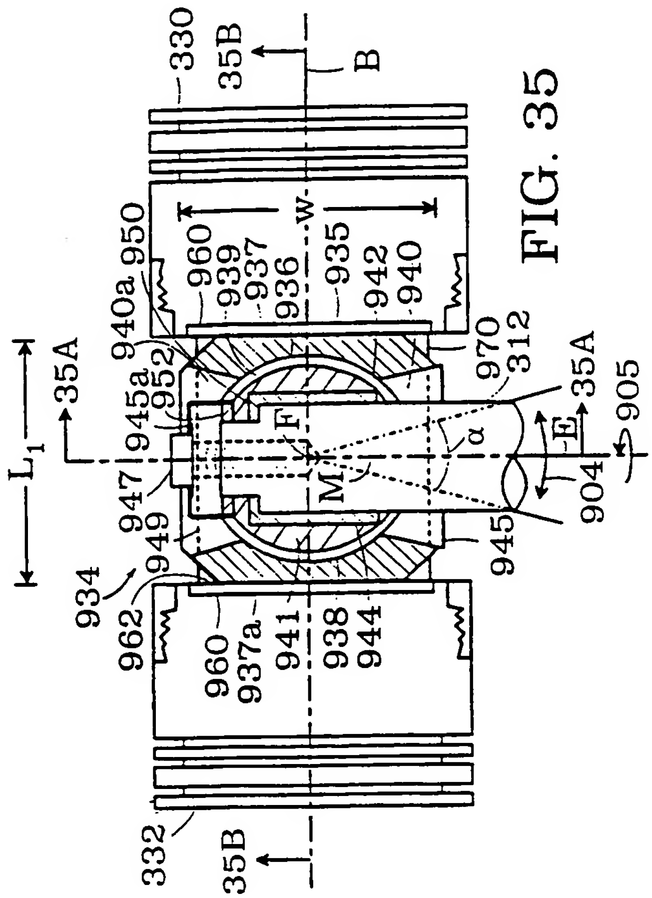


FIG. 35

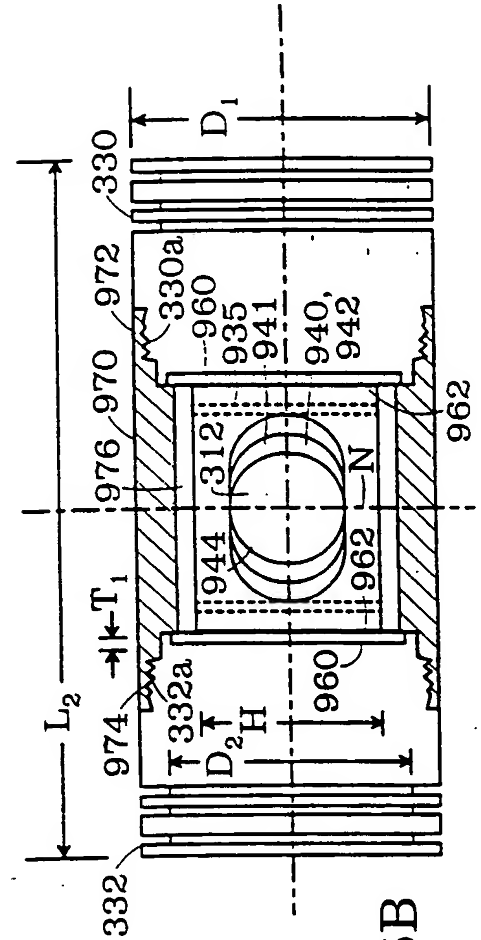


FIG. 35B

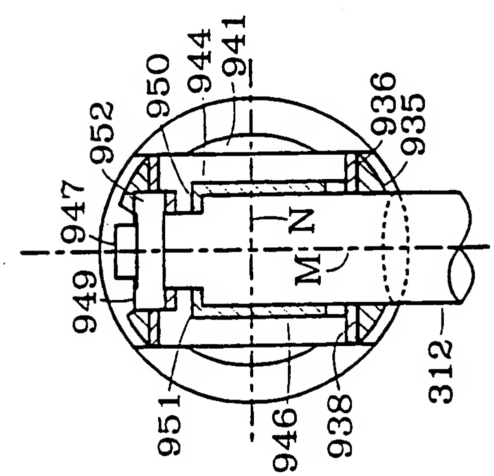


FIG. 35A

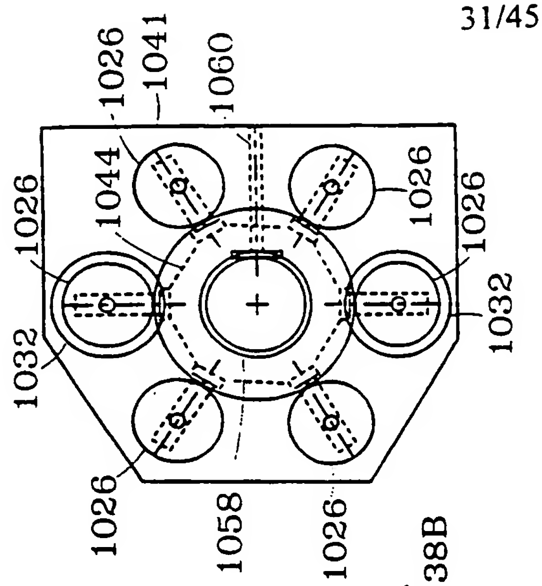


FIG. 38A

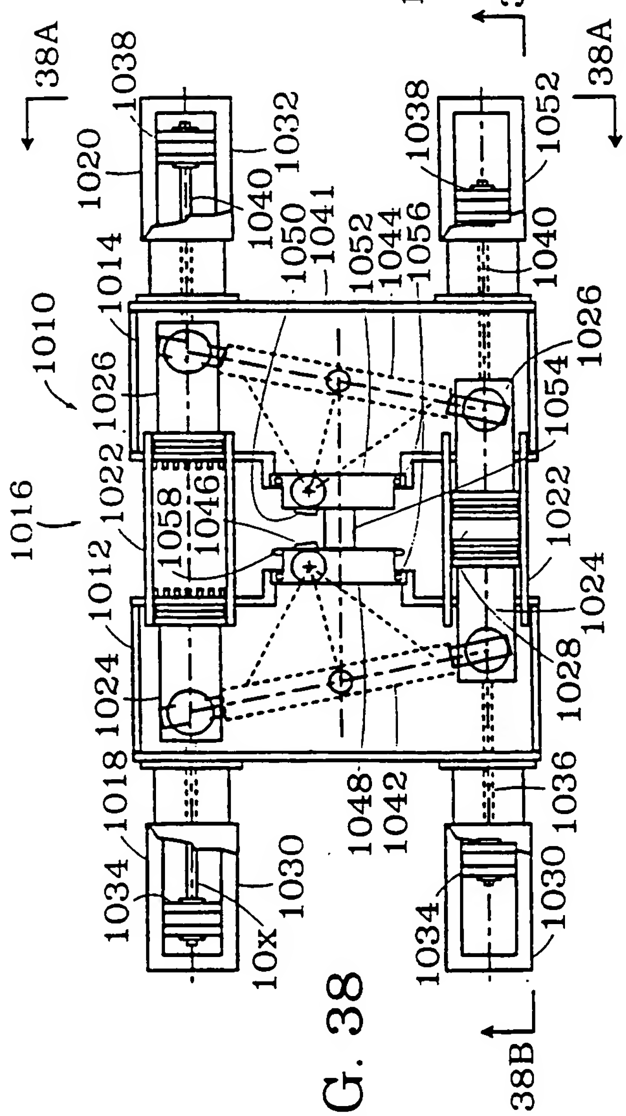


FIG. 38

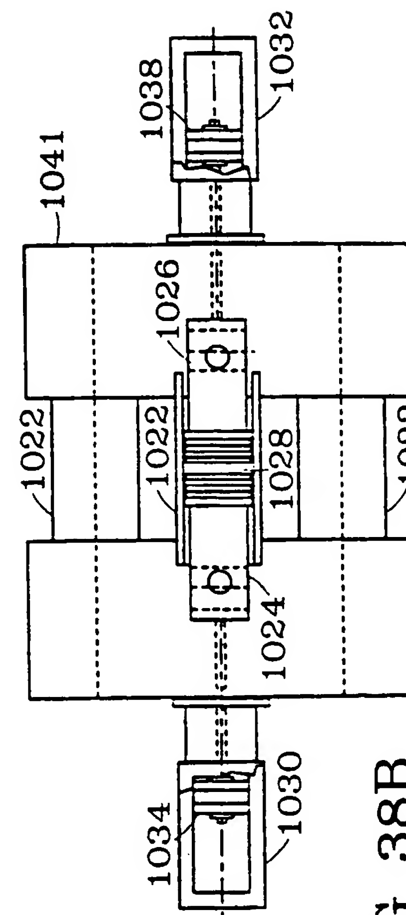


FIG. 38B

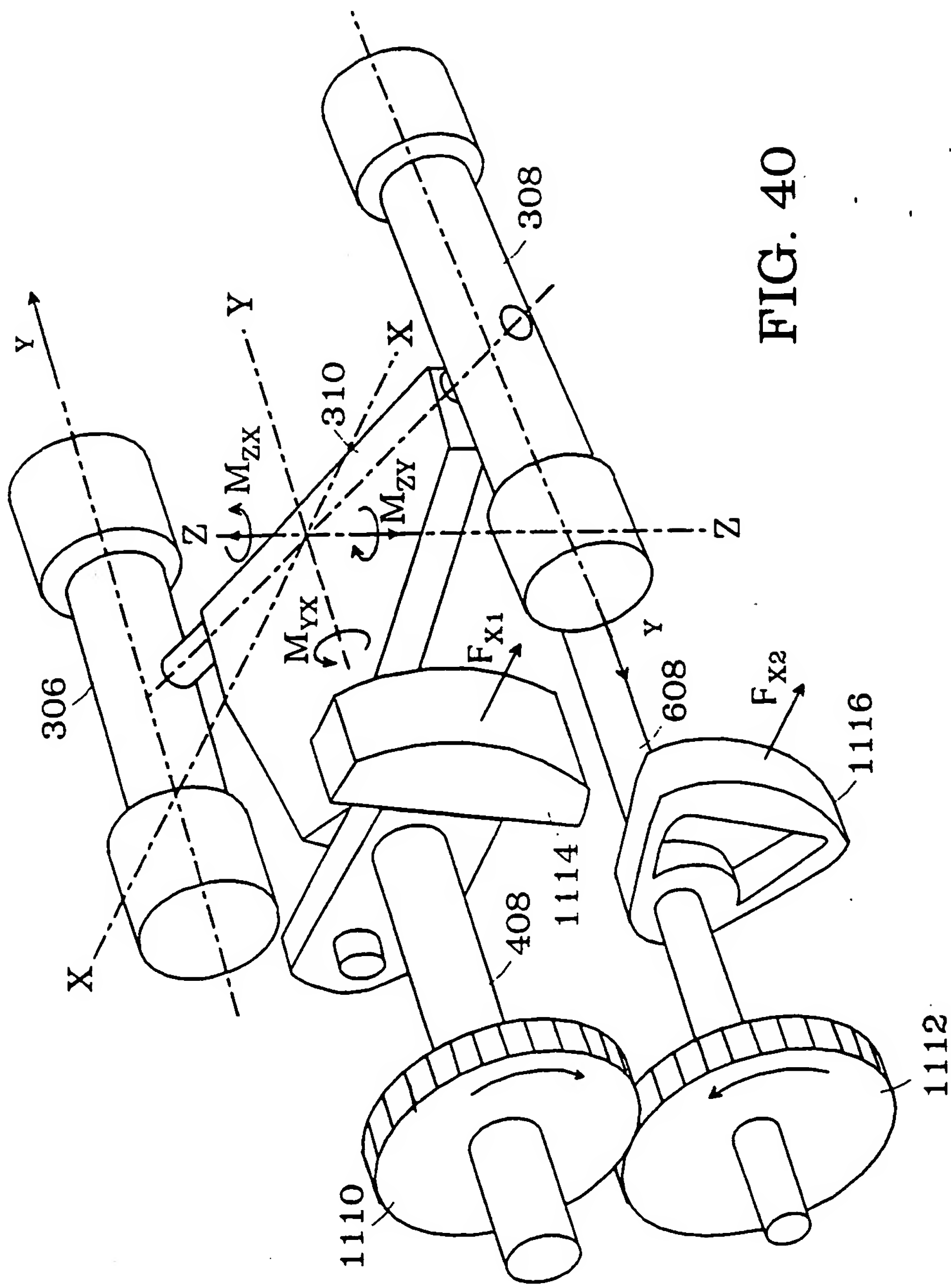
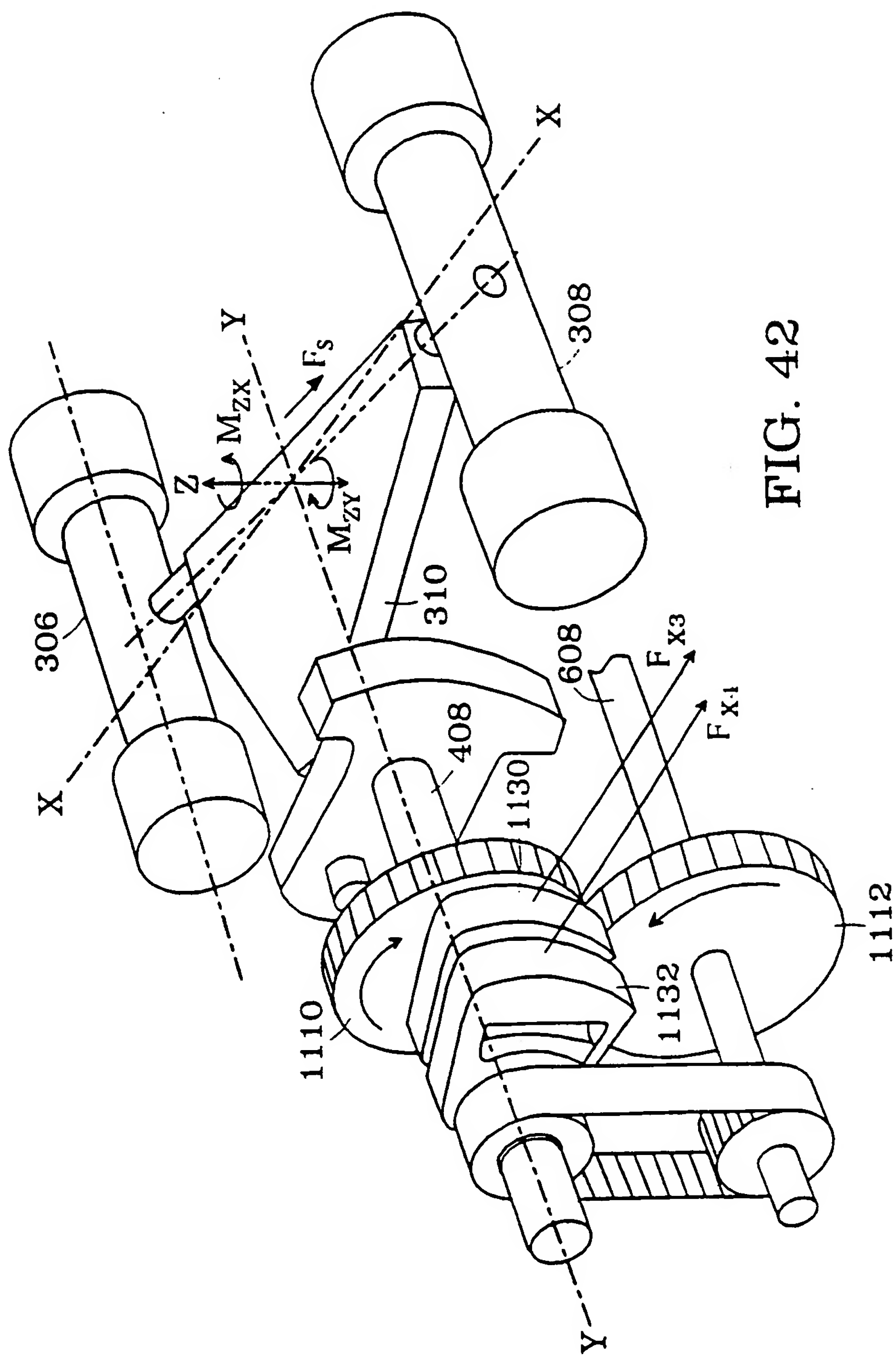

308
Y
Y
X
310
M_{ZX}
M_{ZY}
Z
Z
Y
M_{YX}
F_{X1}
306
608
F_{X2}
1116
1114
408
X
1110
1112

FIG. 40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M_{ZX}
M_{ZY}
F_S
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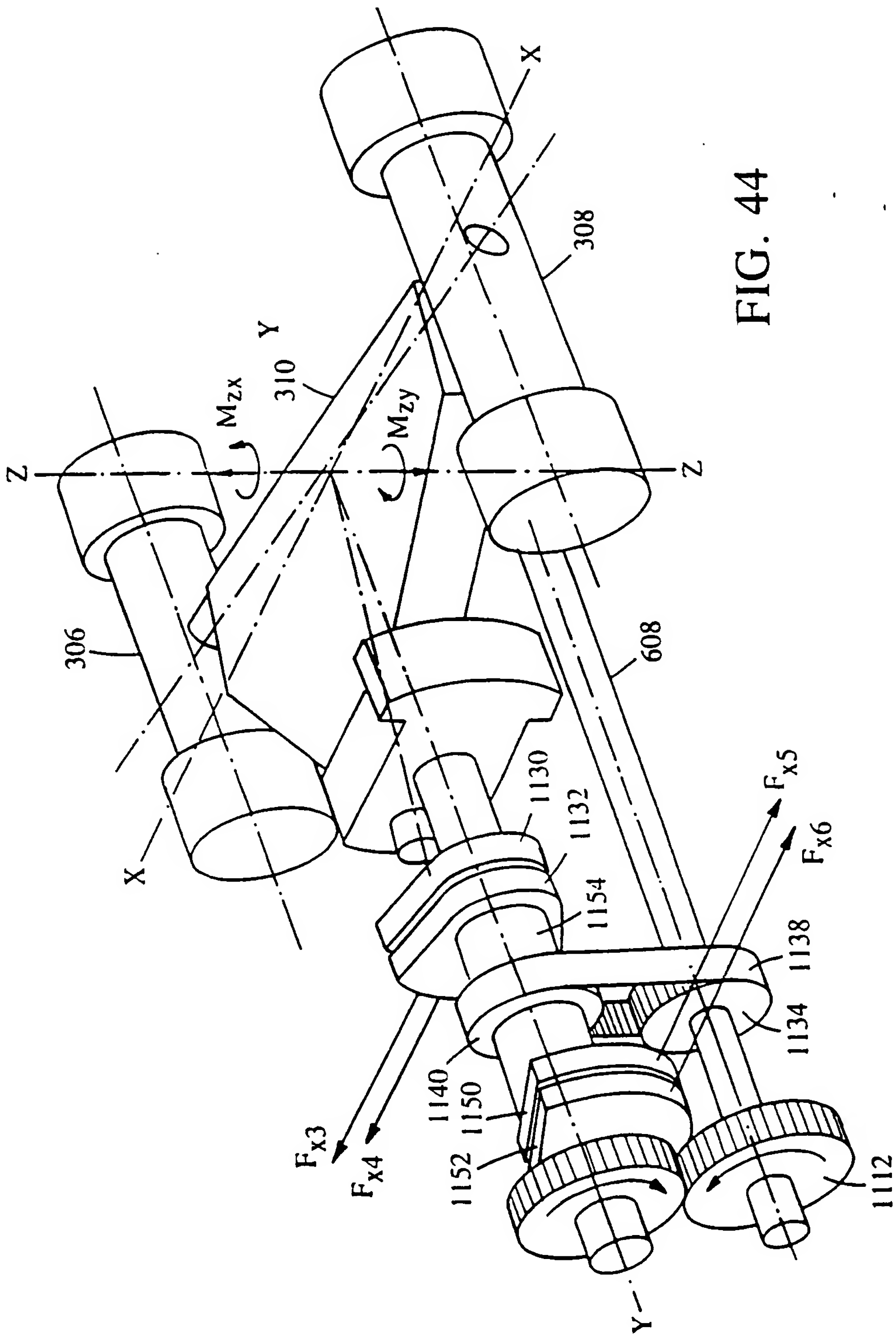
608
F_{X3}
F_{X1}
1130
1132
1110
1112

FIG. 42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Z
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M_{zy}
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608
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1150
1152
1112
F_{x3}
F_{x4}
F_{x5}
F_{x6}

FIG. 44

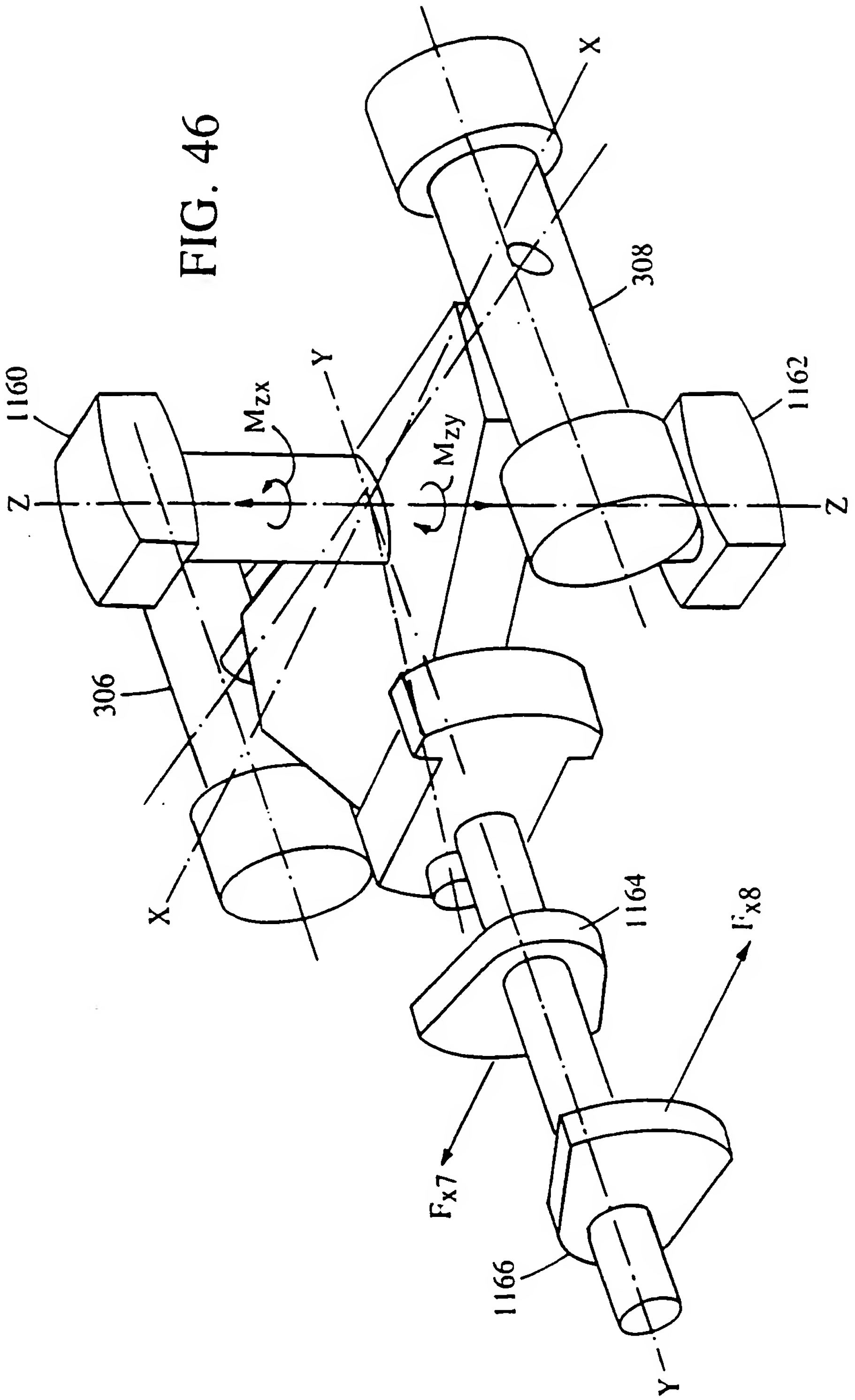
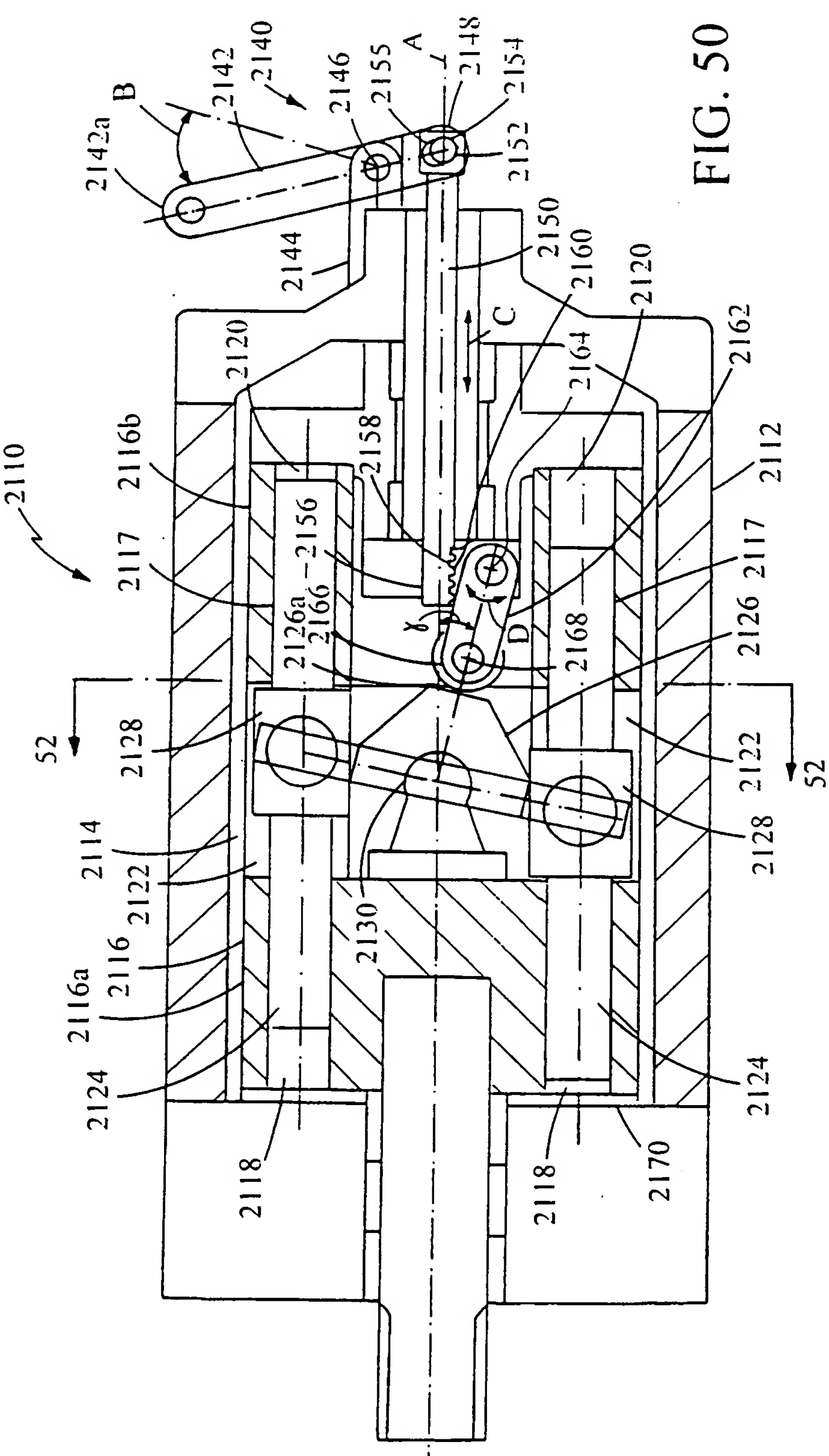


FIG. 46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2170
A
B
C
D
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FIG. 50

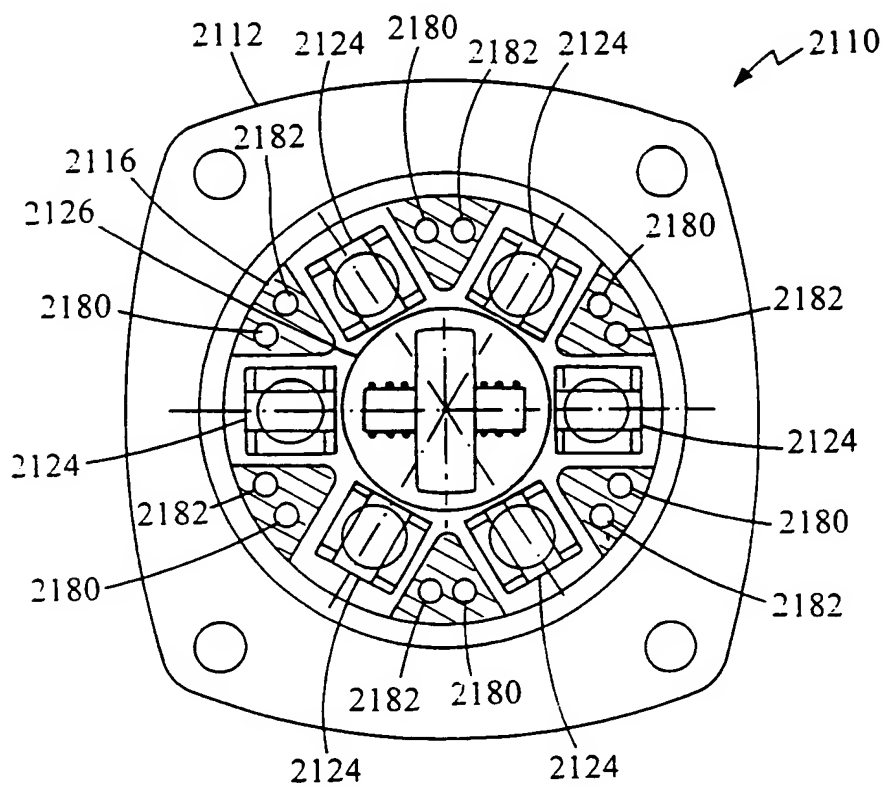
2112
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FIG. 52

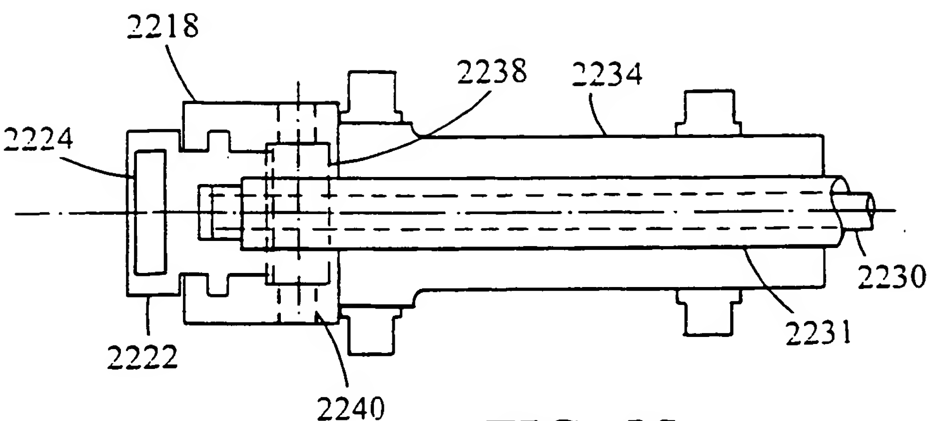

FIG. 55

INTERNATIONAL SEARCH REPORT

Int tional Application No
PCT/US 00/21245

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99 14471 A (SANDERSON MANAGEMENT INC R ;SANDERSON ROBERT A (US)) 25 March 1999 (1999-03-25) figures 1,22 abstract	1,14-19, 28

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Filed on 24 March 2000 (24.03.2000)
US 09/369,013 (CON)
Filed on 5 August 1999 (05.08.1999)

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(72) Inventor; and
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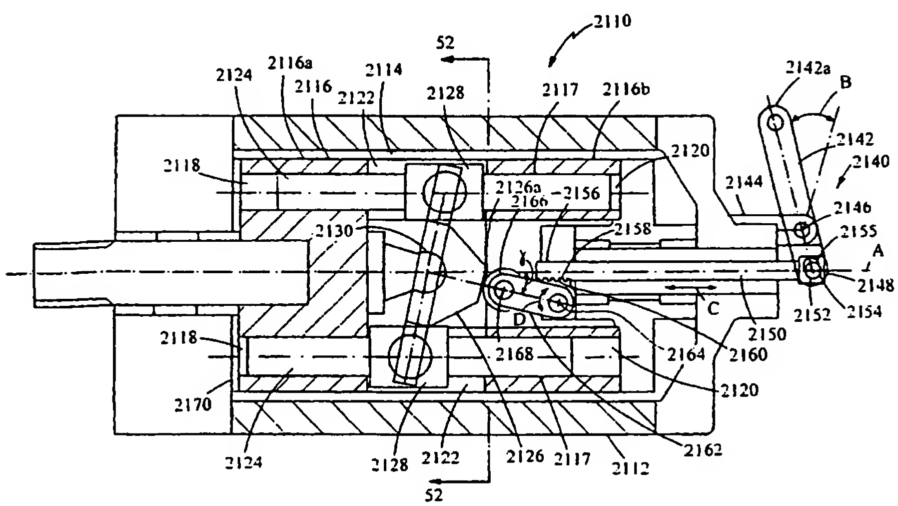
(54) Title: PISTON ASSEMBLY



(57) Abstract: A hydraulic pump includes a housing, at least two pistons mounted to the housing to rotate relative to the housing, and a transition arm coupled to each of the pistons to rotate therewith. The transition arm is set at a predetermined angle relative to a longitudinal axis of the pump. An adjustment mechanism sets the transition arm at the predetermined angle. A cylinder is mounted within the housing to rotate relative to the housing and defines pump cavities for receiving the pistons. A face valve defines inlet and outlet channels in fluid communication with the pump cavities. An apparatus for varying the output volume of a piston assembly includes at least two pistons, a transition arm coupled to each of the at least two pistons, and a rotatable member. The transition arm includes a nose pin, and the rotatable member is coupled to the transition arm nose pin. A radial position of the nose pin relative to an axis of rotation of the rotatable member is adjustable while the rotatable member remains axially stationary.

WO 01/011237 A1